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A DIGITAL ALGORITHM FOR COMPOSITE LAMINATE ANALYSIS - FORTRAN

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STEPHEN W. TSAI, Project Engineer & Chief
Mechanics and Surface Interactions Branch
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FOR THE COMMANDER

F. D. CHERRY, Chief
Nonmetallic Materials Division

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The computer programs contained in this technical report are theoretical and in no way reflect any Air Force owned software programs.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Composite Laminates	Classical Laminated Plate Theory	Hybrid
Modulus	Inplane Coupling Ratios	Moisture
Compliance	Strength	Temperature
Tensor Polynomial Failure	Lamina	FORTRAN
Criterion	Young's Modulus, Poisson's Ratio	Plots, CALCOMP

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents a FORTRAN computer code for the solution of composite materials problems. The computer program can conduct the point stress analysis of general laminates including hybrid laminates. The effect of hygrothermal and mechanical loads on the strength of composite laminates can be studied using this program. Strength predictions on the basis of six commonly used failure theories can be done. Plotting capabilities have been included—using CALCOMP Plotter to obtain the failure envelopes in different loading planes for all the failure theories. (Continued on reverse)

A complete listing of the computer program is given. A number of typical laminates have been treated for numerical and graphical illustrations. Input and output parameters are explained in detail. The algorithm is written in an easily understandable format. Material properties for five different materials are stored in the program (see Table 1). The required material can be used by giving the material name for pure laminates and material property identification number in the layers data card for hybrid laminates. These quantities are given in SI units. If the results are desired in English units (i.e., Psi etc.) a unit identification command has to be used in the appropriate place. This program is a modified version of an earlier program given in AFWAL-TR-81-4073.

FOREWORD

This report describes the inhouse effort conducted in the Mechanics and Surface Interactions Branch (MLBM), Nonmetallic Materials Division (MLB), Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under the contract #F33615-83-C-5056 with the University of Dayton Research Institute.

The work reported herein was performed during the period 1 July 1982 to 31 June 1983. Dr. Stephen W. Tsai (AFWAL/MLBM) was the Project Engineer.

This report is a modified version of AFWAL-TR-81-4073.

The author wishes to express his deep sense of gratitude to Dr. S. W. Tsai for his extremely fruitful guidance in the course of this work. Figures 1 - 2 and Tables 1 - 7 have been taken from the book, "Introduction to Composite Materials," by S. W. Tsai and H. T. Hahn with their permission.

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LIST OF ILLUSTRATIONS (CONTINUED)

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LIST OF SUBROUTINES

1. ADJUST: Adjust the arrays for plots in qr space
2. AMAX: Picks up the maximum value in a vector
3. AMIN: Picks up the minimum value in a vector
4. COEF: Calculate G_{ij} and G_i after transformation
5. FAILCO: Coefficients G_{ij} and G_i for tensor polynomial failure criterion
6. FSFTY: Strength ratios R and $\bar{R}$
7. INVRS: Inverse of Q as A
8. LMDT: Contains the values of elastic constants for different materials
9. LMNT: Laminate description
10. MATM: Matrix multiplication, C = AxB
11. MINP: Translates material name to material property identification number
12. MODCM: Off-axis modulus Q_{ij}
13. MODULS: Ply on-axis modulus Q_{ij} and invariants U_i $(i = 1,5)$
14. MOLS: Effective in-plane modulus A, Flexural modulus D, and coupling B matrices; nonmechanical stress and moment resultants
15. MTAD: Addition of a matrix to a scalar multiple of another matrix; C = A + Con x B, Con is scalar
16. MTDM: Translates material properties to each ply
17. MVM: Matrix and vector multiplication Z = X x Y
18. MXSTRN: Strength prediction on the basis of max. strain failure theory
19. MXSTRS: Strength prediction on the basis of max. stress failure theory
20. NMSN: Nonmechanical strain (e_x, e_y, e_{xy})

LIST OF SUBROUTINES (CONTINUED)

LIST OF FUNCTIONS

VVM = Row Vector to Column Vector Multiplication

SINM = $\sin(\theta)$

COSM = $\cos(\theta)$

SECTION I
INTRODUCTION

This report presents a FORTRAN computer code for the solution of composite materials problems.[+] The computer program can conduct the point stress analysis of general laminates including hybrid laminates. The effect of hygrothermal and mechanical loads on the strength of composite laminates can be studied using this program. The analytical formulas based on the lamination theory have been used. These formulas are available in Reference 1. For the sake of completeness, the relevant relations are presented in this report. All the notations used in References 1 and 2 are followed. Plotting capabilities to investigate the in-plane strength of layered composites based upon six commonly used failure theories have been incorporated. A large number of options to obtain failure surfaces are included. CALCOMP plotter is used.

This manual has been written to provide the users results for their problems with a minimum of effort. The input instructions are explained in detail and are supported with examples. Material properties of five well-known composite materials are stored in the program and can be used by giving the relevant material name for pure laminates and by giving the material property identification number for hybrid laminates. The material properties which are not included in the program can be used through the input data. In such a case, new material properties will take the storage space provided for already-stored material property data; and, therefore, the corresponding material names or material property identification numbers are to be used for further calculations in that computer run. The new materials are to be supplied in SI units, according to the units used in Table 1, while the output can be obtained in English units. For obtaining results in English units, a command at appropriate place has to be given. For pure materials, this command is ENGLISH at the 11th column of the material card and for hybrid laminates, IUNIT = 2 in the $LAYERS card.

On the basis of six commonly used failure theories, the in-plane strength characteristics of multidirectional composite laminates can be investigated. In the case of maximum stress and maximum strain failure theories,

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[+]Modified version of AFWAL-TR-81-4073[12]

TABLE 1

MATERIAL PROPERTIES GIVEN IN LAMDATA

LMPI	1	2	3	4	5	6	7
MATERIAL PROPERTY	T300/5208 GRAPH/EP	B4/5505 BORON/EP	AS/3501 GRAPH/EP	SCOTCHPLY 1002 GLASS/EP	KEVLAR49 ARAMID/EP	CORE	ALUMINUM
E_X (GPa)	181.0	204.0	138.0	38.6	76.0	0.0	69.0
E_Y (GPa)	10.3	18.5	8.96	8.27	5.5	0.0	69.0
ν_X	0.28	0.23	0.3	0.26	0.34	0.0	0.3
E_S (GPa)	7.17	5.59	7.1	4.14	2.3	0.0	26.5
α_X (μm/m)/k	0.02	6.1	-0.3	8.6	-4.0	0.01	-
α_Y (μm/m)/k	22.5	30.3	28.1	22.1	79.0	12.5	-
β_X (m/m)	0.0	0.0	0.0	0.0	0.0	0.0	-
β_Y (m/m)	0.6	0.6	0.44	0.6	0.6	0.09	-
X (MPa)	1500.0	1260.0	1447.0	1026.0	1400.0	0.09	400.0
X′ (MPa)	1500.0	2500.0	1447.0	610.0	235.0	0.09	400.0
Y (MPa)	40.0	61.0	51.7	31.0	12.0	0.09	400.0
Y′ (MPa)	246.0	202.0	206.0	118.0	53.0	0.09	400.0
S (MPa)	68.0	67.0	93.0	72.0	34.0	0.09	230.0
h_0 (M)	125E-6	125E-6	125E-6	125E-6	125E-6	0.001	1.0

FOR A SANDWICH CORE IN A LAMINATE LMPI=6. IF NECESSARY NONZERO CORE PROPERTIES CAN BE GIVEN. THESE VALUES ARE TAKEN FROM 'INTRODUCTION TO COMPOSITE MATERIALS' BY S.W. TSAI AND H.T. HAHN.

strength prediction of hygrothermal loads are not included. However, one can calculate that on the basis of mechanical and nonmechanical stress and strain components calculated for other failure theories, or for these failure theories.

A list of other computer codes for composite laminate analysis developed at the Air Force Wright Aeronautical Laboratories, Materials Laboratory is given in the Appendix.

SECTION II

STIFFNESS PROPERTIES

1. UNIDIRECTIONAL LAMINATE STRESS STRAIN RELATIONS

The stiffness of unidirectional composites can be defined by appropriate stress strain relations. These relations can be expressed in terms of engineering constants, compliance components or modulus components. A detailed treatise on mechanics of composites is given in Reference 1. For completeness the relevant relations are given in the present report. All the notations used in Reference 1 are followed in this research.

The two key stress strain relations for a unidirectional composite are given in Tables 2 and 3:

TABLE 2

ON-AXIS STRESS STRAIN RELATIONS - COMPLIANCE

	σ_x	σ_y	σ_s
ϵ_x	S_{xx}	S_{xy}	
ϵ_y	S_{yx}	S_{yy}	
ϵ_s			S_{ss}

TABLE 3

ON-AXIS STRESS STRAIN RELATIONS - MODULUS

	ϵ_x	ϵ_y	ϵ_s
σ_x	Q_{xx}	Q_{xy}	
σ_y	Q_{yx}	Q_{yy}	
σ_s			Q_{ss}

In the foregoing matrix multiplication table, each value in the first column is equal to the sum of products of corresponding row elements with their column headings. This rule should be self-evident.

$\{\sigma_x, \sigma_y, \sigma_s\}$ = {Longitudinal, transverse, shear} stress components in the xy - plane

$\{\varepsilon_x, \varepsilon_y, \varepsilon_s\}$ = {Longitudinal, transverse, shear} stress components in the xy - plane

Q_{ij} = Modulus components

S_{ij} = Compliance components

$$
\begin{aligned}
S_{xx} &= 1/E_x \\
S_{yy} &= 1/E_y \\
S_{xy} &= -\nu_y/E_y \\
S_{yx} &= -\nu_x/E_x \\
S_{ss} &= 1/E_s \\
Q_{xx} &= mE_x \\
Q_{yy} &= mE_y \\
Q_{xy} &= mE_x\nu_y \\
Q_{yx} &= mE_y\nu_x \\
Q_{ss} &= E_s \\
m &= 1/(1-\nu_y\nu_x)
\end{aligned}
\tag{1}
$$

where

E_x = Longitudinal Young's modulus

E_y = Transverse Young's modulus

ν_x = Longitudinal Poisson's ratio $= -\dfrac{\varepsilon_y}{\varepsilon_x}$

ν_y = Transverse Poisson's ratio $= -\dfrac{\varepsilon_x}{\varepsilon_y}$

E_s = Longitudinal shear modulus $= \dfrac{\sigma_s}{\varepsilon_s}$

All the material constants of the stress strain relation shown previously are called engineering constants. They are the familiar constants used for conventional materials with subscript added to denote directionality of properties. Thus, the use of engineering constants will often facilitate the use of composites for structural applications. However, it has been found more convenient to use compliance and modulus components of multidirectional composites. In Equation 1 S_{ij} are compliance components and Q_{ij} are modulus components.

Subroutine MODULS calculates the modulus matrix Q_{ij}.

2. TRANSFORMATION OF STRESS AND STRAIN

The change of stiffness of unidirectional composites as a function of ply orientation is a unique feature of composites. These orientational variations of stress and strain are the fundamental underlying issues which must be understood. The relations governing these variations are called transformation equations and are given in Tables 4 and 5:

TABLE 4

STRESS TRANSFORMATION RELATIONS

	σ_1	σ_2	σ_6
σ_x	m^2	n^2	$2mn$
σ_y	n^2	m^2	$-2mn$
σ_s	$-mn$	mn	$m^2 - n^2$

$m = \cos\theta$, $n = \sin\theta$

TABLE 5

STRAIN TRANSFORMATION RELATIONS

	ε_1	ε_2	ε_6
ε_x	m^2	n^2	mn
ε_y	n^2	m^2	$-mn$
ε_s	$-2mn$	$2mn$	$m^2 - n^2$

Where σ_1, σ_2, σ_6 are off-axis stress components, σ_x, σ_y, σ_s, are transformed on-axis stress components and Θ is the angle of counter-clockwise rotation of the on-axis laminate (Figure 1).

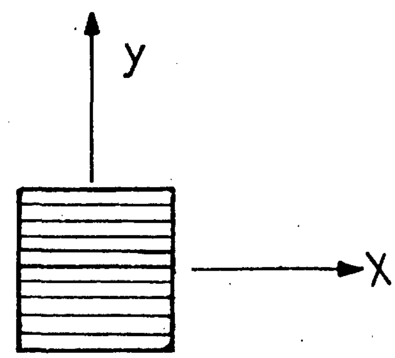

Figure 1(a). Material Symmetry Axis of a Unidirectional Composite

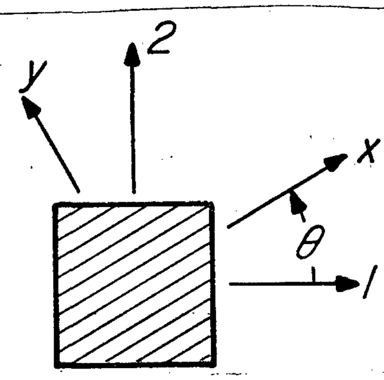

Figure 1(b). Off-Axis Configuration of a Unidirectional Composite, Counter Clockwise Rotation Is Positive

Similarly ε_1, ε_2, ε_6 are off-axis and ε_x, ε_y, ε_s are on-axis strain components.

Subroutine TRS calculates the transformed stress components.

Subroutine TRE calculates the transformed strain components.

3. OFF-AXIS MODULUS

Because the composite laminates are made of off-axis and on-axis plys, the stiffness of off-axis ply orientation must be understood. The off-axis modulus of a ply can be determined in three steps: (1) the off-axis to on-axis strain transformation, (2) the on-axis stress strain relation, and (3) the on-axis to off-axis stress transformation. This process is initiated by a given strain in Figure 2(a) and eventually leads us to the induced stress in Figure 2(d). The three transformations mentioned above, when combined together, will yield the required off-axis modulus and off-axis stress strain relations for arbitrary angle of rotation.

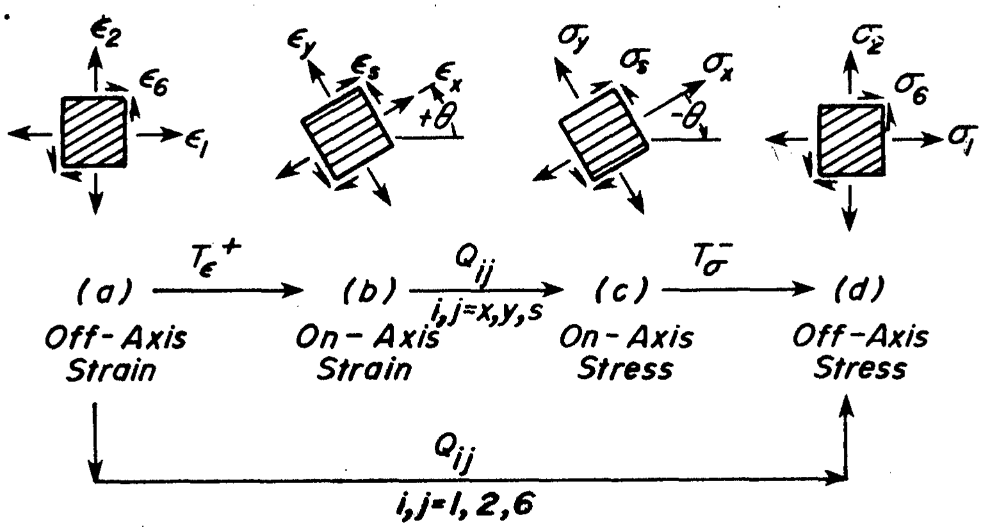

Figure 2. Determination of Off-Axis Modulus

From (a) - (b): Use positive angle Θ strain transformations

From (b) - (c): Use the on-axis stress strain relations in modulus

From (c) - (d): Use inverse stress transformation.

Following the above tranformations and making some mathematical simplifications, off-axis stress strain relations can be obtained, i.e., Table 6.

TABLE 6

OFF-AXIS STRESS STRAIN RELATIONS

	ε_1	ε_2	ε_6
σ_1	Q_{11}	Q_{12}	Q_{16}
σ_2	Q_{21}	Q_{22}	Q_{26}
σ_6	Q_{61}	Q_{62}	Q_{66}

The off-axis modulus components are given in the matrix form shown in Table 7.

TABLE 7

MODULUS COMPONENTS Q_{ij}

	1	U_2	U_3
Q_{11}	U_1	$\cos 2\theta$	$\cos 4\theta$
Q_{22}	U_1	$-\cos 2\theta$	$\cos 4\theta$
Q_{12}	U_4		$-\cos 4\theta$
Q_{66}	U_5		$-\cos 4\theta$
Q_{16}		$\frac{1}{2}\sin 2\theta$	$\sin 4\theta$
Q_{26}		$\frac{1}{2}\sin 2\theta$	$-\sin 4\theta$

Where

$$
\begin{aligned}
U_1 &= (3Q_{xx} + 3Q_{yy} + 2Q_{xy} + 4Q_{ss})\ /8 \\
U_2 &= (Q_{xx} - Q_{yy})\ /2 \\
U_3 &= (Q_{xx} + Q_{yy} - 2Q_{xy} - 4Q_{ss})\ /8 \\
U_4 &= (Q_{xx} + Q_{yy} + 6Q_{xy} - 4Q_{ss})\ /8 \\
U_5 &= (Q_{xx} + Q_{yy} - 2Q_{xy} + 4Q_{ss})\ /8
\end{aligned}
\qquad (2)
$$

4. MODULUS AND COMPLIANCE OF GENERAL LAMINATES

According to the classical laminated plate theory, the strain components are considered to vary linearly along the thickness of the laminate, i.e.,

$$\begin{aligned}\varepsilon_1(z) &= \varepsilon_1^0 + zk_1\\ \varepsilon_2(z) &= \varepsilon_2^0 + zk_2\\ \varepsilon_6(z) &= \varepsilon_6^0 + zk_6\end{aligned} \tag{3}$$

where ε_i^0 $(i = 1,2,6)$ are mid plane strain components and k_i $(i=1,2,6)$ are the corresponding curvatures.

A general laminate may contain plys of the same material or different materials (hybrid). The effective modulus of the composite laminate is considered to be an arithmetic average of the modulus of the constituent plys. Simple formulas can be derived to compute the effective stress strain relationship in terms of the modulus of constituent plys. The stress strain relation for a general laminate is given by:

$$\begin{bmatrix} N_1 \\ N_2 \\ N_6 \\ M_1 \\ M_2 \\ M_6 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{21} & A_{22} & A_{26} & B_{21} & B_{22} & B_{26} \\ A_{61} & A_{62} & A_{66} & B_{61} & B_{62} & B_{66} \\ & B & & D_{11} & D_{12} & D_{16} \\ & & & D_{21} & D_{22} & D_{26} \\ & & & D_{61} & D_{62} & D_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1^0 \\ \varepsilon_2^0 \\ \varepsilon_6^0 \\ k_1 \\ k_2 \\ k_6 \end{bmatrix} - \begin{bmatrix} N_1^N \\ N_2^N \\ N_6^N \\ M_1^N \\ M_2^N \\ M_6^N \end{bmatrix} \tag{4}$$

where N_1, N_2, N_6 are stress resultants over the thickness (h) of the laminate and M_1, M_2 and M_6 are corresponding moment resultants. These parameters are defined as follows:

$$N_i = \int_{-h/2}^{h/2} \sigma_i \, dz$$

$$N_i = \int_{-h/2}^{h/2} Q_{ij}\varepsilon_j^0\, dz + \int_{-h/2}^{h/2} Q_{ij}k_j z dz \quad (i \;\&\; j = 1,2,6)$$

or

$$N_i = A_{ij}\varepsilon_j^0 + B_{ij}k_j \tag{5}$$

and

$$M_i = \int_{-h/2}^{h/2} \sigma_i\, zdz$$

or

$$M_i = \int_{-h/2}^{h/2} Q_{ij}\varepsilon_j^0 zdz + \int_{-h/2}^{h/2} Q_{ij}k_j z^2 dz$$

or

$$M_i = B_{ij}\varepsilon_j^0 + D_{ij}k_j \tag{6}$$

$$N_i^N = \int_{-h/2}^{h/2} Q_{ij}e_j\, dz \tag{7}$$

$$M_i^N = \int_{-h/2}^{h/2} Q_{ij}\, e_j\, zdz$$

$$e_i = \Delta T\alpha_i + c\beta_i \qquad (i=x,y)$$

$$e_s = 0$$

Where h is the thickness of the laminate and e_i (i=x,y,s) are nonmechanical strain components, α_i and β_i are coefficients of thermal expansion and swelling coefficients respectively, ΔT is the temperature difference and

c is the moisture contents. In the foregoing relations the summation over the range of repeated subscript will be understood. Figure 3 shows a reference frame for numbering the layers. The detailed explanation to these equations is given in Reference 1.

Subroutine NMSN calculates the nonmechanical strain components for each layer.

Subroutine MOLS calculates the effective inplane modulus matrix A, effective flexural modulus D, coupling matrix B, nonmechanical stress, and moment resultants.

The constitutive equations (Equation 4) can be rewritten in the following form:

$$\begin{bmatrix} \underset{\sim}{\varepsilon}^{0} \\ \underset{\sim}{k} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{\alpha} & \underset{\sim}{\beta} \\ \underset{\sim}{\beta}^{T} & \underset{\sim}{\delta} \end{bmatrix} \times \begin{bmatrix} \underset{\sim}{N} + \underset{\sim}{N}^{N} \\ \underset{\sim}{M} + \underset{\sim}{M}^{N} \end{bmatrix} \tag{8}$$

where

$$\underset{\sim}{\alpha} = \text{Inplane compliance} = \underset{\sim}{a} + \underset{\sim}{a}\underset{\sim}{B}\,(\underset{\sim}{D}-\underset{\sim}{B}\underset{\sim}{a}\underset{\sim}{B})^{-1}\,\underset{\sim}{B}\underset{\sim}{a}$$

$$\underset{\sim}{\beta} = \text{Coupling compliance} = -\underset{\sim}{a}\underset{\sim}{B}\,(\underset{\sim}{D}-\underset{\sim}{B}\underset{\sim}{a}\underset{\sim}{B})^{-1}$$

$$\underset{\sim}{\delta} = \text{Flexural compliance} = (\underset{\sim}{D}-\underset{\sim}{B}\underset{\sim}{a}\underset{\sim}{B})^{-1}$$

$$\underset{\sim}{a} = \underset{\sim}{A}^{-1}$$

It has been shown (Reference 2), that the use of normalized quantities in the stress strain relations is very helpful in understanding the variation in effective material properties of composite laminates due to the

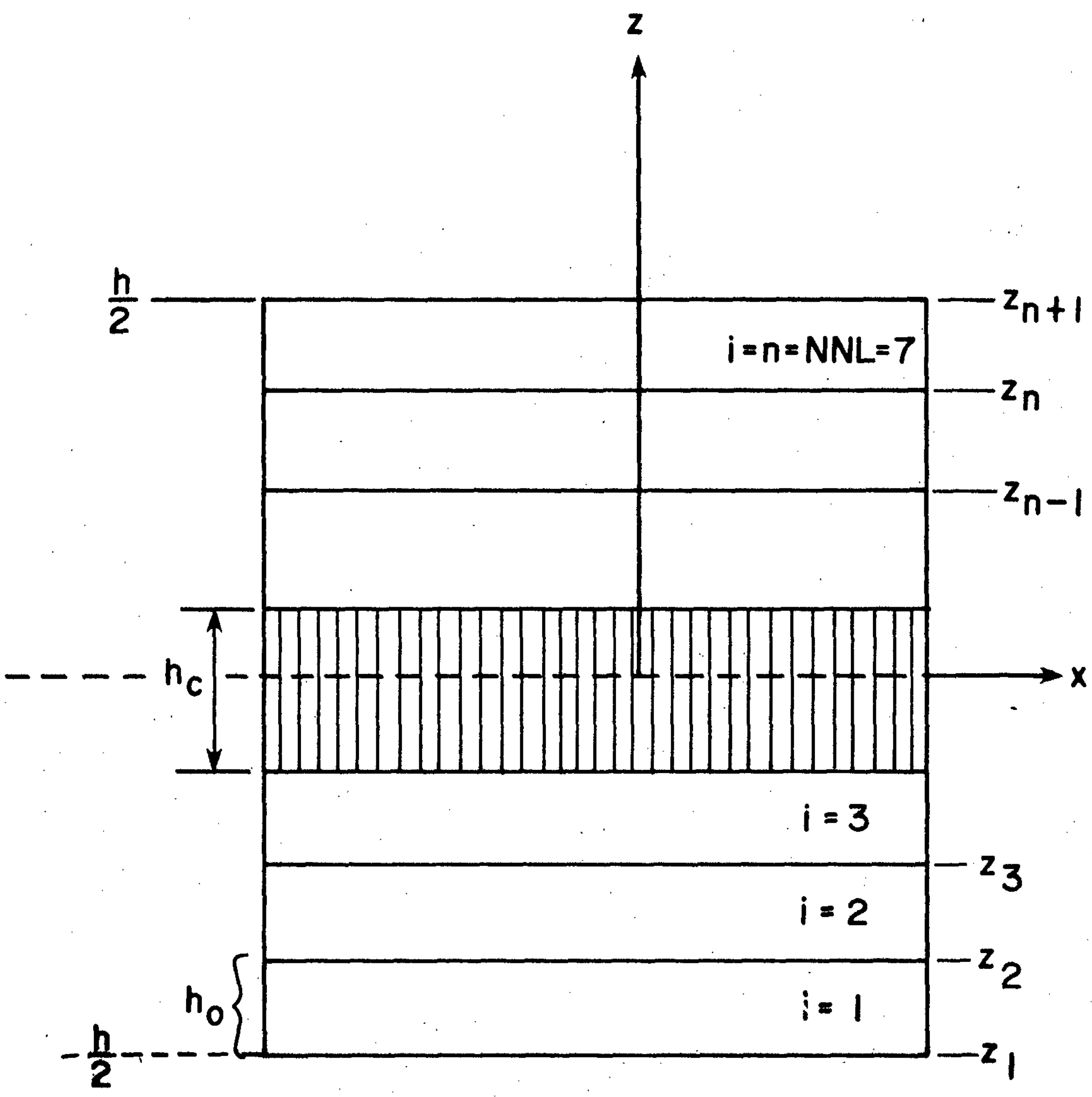

Figure 3. Reference Frame for Locating Different Plys in the Laminate

change in ply properties, orientations or volume fractions. The following normalization has been suggested:

$$
\begin{aligned}
\underset{\sim}{N}^* &= \frac{1}{h}\,\underset{\sim}{N} \\
\underset{\sim}{M}^* &= \frac{6}{h^2}\,\underset{\sim}{M} \\
\underset{\sim}{k}^* &= \frac{h}{2}\,\underset{\sim}{k} \\
\underset{\sim}{A}^* &= \frac{1}{h}\,\underset{\sim}{A} \\
\underset{\sim}{D}^* &= \frac{12}{h^3}\,\underset{\sim}{D} \\
\underset{\sim}{B}^* &= \frac{2}{h^2}\,\underset{\sim}{B} \\
\underset{\sim}{\alpha}^* &= h\underset{\sim}{\alpha} \\
\underset{\sim}{\beta}^* &= \frac{h^2}{2}\,\underset{\sim}{\beta} \\
\underset{\sim}{\delta}^* &= \frac{h^3}{12}\,\underset{\sim}{\delta} \\
\underset{\sim}{N}^{N*} &= \frac{1}{h}\,\underset{\sim}{N}^N \\
\underset{\sim}{M}^{N*} &= \frac{6}{h^2}\,\underset{\sim}{M}^N
\end{aligned}
\tag{9}
$$

With the aid of these normalized parameters the stress strain relations (Equation 4), reduce to the following form:

$$
\begin{bmatrix} \underset{\sim}{N}^* \\ \underset{\sim}{M}^* \end{bmatrix} = \begin{bmatrix} \underset{\sim}{A}^* & \underset{\sim}{B}^* \\ 3\underset{\sim}{B}^* & \underset{\sim}{D}^* \end{bmatrix} \begin{bmatrix} \underset{\sim}{\varepsilon}^* \\ \underset{\sim}{k}^* \end{bmatrix} - \begin{bmatrix} \underset{\sim}{N}^{N*} \\ \underset{\sim}{M}^{N*} \end{bmatrix} \tag{10}
$$

and

$$
\begin{bmatrix} \underset{\sim}{\varepsilon}^* \\ \underset{\sim}{k} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{\alpha}^* & 1/3\ \underset{\sim}{\beta}^* \\ \underset{\sim}{\beta}^{*T} & \underset{\sim}{\delta}^* \end{bmatrix} \begin{bmatrix} \underset{\sim}{N}^* + \underset{\sim}{N}^{N*} \\ \underset{\sim}{M}^* + \underset{\sim}{M}^{N*} \end{bmatrix} \tag{11}
$$

In these equations, the multiplying factors 3 and 1/3 are consequent to the normalization factors defined in Equation 9. The well known Kirchhoff's assumption in classical plate theory of the linear strain distribution along the ply thickness, can be stated as:

$$\varepsilon_i = \varepsilon_i^{\circ} + z^* k_i^* \qquad (i = 1,2,6) \tag{12}$$

where $z^* = 2z/h$ and $-1<z^*<1$

Thus, all the equations required for computing the effective modulus matrix are given.

5. INPLANE AND FLEXURAL ENGINEERING CONSTANTS

a. Inplane

The inplane stress strain relation can be written in the following form:

$$\underset{\sim}{N}^* = \underset{\sim}{A}^* \underset{\sim}{\varepsilon}^*$$

or

$$\underset{\sim}{\varepsilon} = \underset{\sim}{a}^* \underset{\sim}{N}^* \quad , \qquad \underset{\sim}{a}^* = (\underset{\sim}{A}^*)^{-1}$$

The typical effective engineering constants are given by:

$$\text{Inplane longitudinal modulus} = E_1^{a} = 1/a^*_{11}$$

$$\text{Inplane transverse modulus} = E_2^{a} = 1/a^*_{22}$$

$$\text{Inplane shear modulus} = E_6^{a} = 1/a^*_{66}$$

$$\text{Inplane Poison's ratio} = \nu_{21}^{a} = -\frac{a^*_{12}}{a^*_{11}}$$

b. Flexural

The moment-curvature relation can be written as:

$$\underset{\sim}{M}^* = \underset{\sim}{D}^* \underset{\sim}{k}^*$$

or

$$\underset{\sim}{k}^* = \underset{\sim}{d}^* \underset{\sim}{M}^* \quad , \quad \underset{\sim}{d}^* = (\underset{\sim}{D}^*)^{-1}$$

The typical effective flexural engineering constants are given by:

Longitudinal Young's modulus = $E_1^f = 1/d^*_{11}$

Transverse Young's modulus = $E_2^f = 1/d^*_{22}$

Shear modulus = $E_6^f = 1/d^*_{66}$

Poisson's ratio = $\nu_{21}^f = -d^*_{12}/d^*_{11}$

In unsymmetric laminates, the effective stress strain relations and moment curvature relations will not be uncoupled. Therefore, in those situations the effective inplane and flexural engineering constants may not give much meaningful information.

6. MATERIAL PROPERTIES FOR FINITE ELEMENT ANALYSIS

The theory used in this report is based upon Kirchhoff's classical plate theory. For the stress analysis of composite laminates by finite element general purpose computer code, NASTRAN, the effective modulus matrix A_{ij}/h is used. In the NASTRAN material property input data card MT2, the numerical values are given such that the notation G_{ij} in the NASTRAN manual represents the effective modulus A_{ij}/h in this report.

SECTION III
FAILURE THEORIES

Figure 4 shows the failure criteria survey response obtained by the AIAA composite materials subcommittee [3]. On the basis of this response we have chosen maximum stress, maximum strain and quadratic polynomial (Tsai-Wu [4], Chamis [5], Hoffman [6], and Hill [7]) failure criteria for a comparative treatment in this work. Reference 8 gives an extensive survey of failure theories. The theories considered in this investigation are given in [9,10,11]. For completeness, these theories are restated here

Maximum Stress	Maximum Strain
$\sigma_x \leq X$	$\varepsilon_x \leq \dfrac{X}{E_x}$
$\sigma_y \leq Y$	$\varepsilon_y \leq \dfrac{Y}{E_y}$
$\sigma_s \leq S$	$\varepsilon_s \leq \dfrac{S}{E_s}$

Failure occurs when one of the equalities is met.

Quadratic Polynomial

Four quadratic polynomial failure criteria given in Table 8, have been considered.

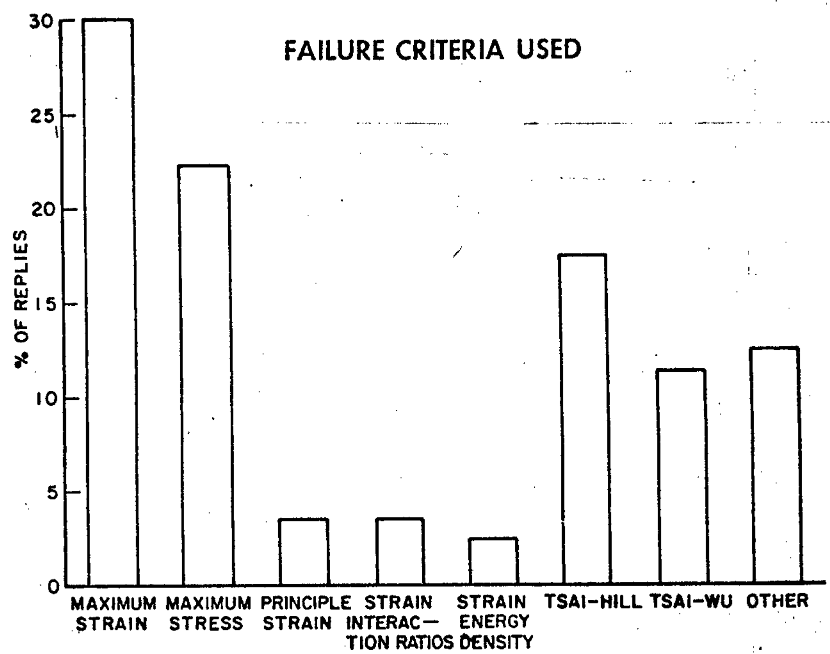

Figure 4. AIAA Failure Criteria Survey.

TABLE 8

QUADRATIC POLYNOMIAL FAILURE CRITERION

Parameter \ Criteria	Tsai-Wu	Chamis	Hoffman	Hill
Equation	$\sigma^T F\sigma + \bar{F}^T\sigma = 1$	$\sigma^T F\sigma = 1$	$\sigma^T F\sigma + \bar{F}^T\sigma = 1$	$\sigma^T F\sigma = 1$
F_{xx}	$\frac{1}{XX'}$	$\frac{1}{X^2}, (\frac{1}{X'^2})^{\dagger}$	$\frac{1}{XX'}$	$\frac{1}{X^2}$
F_{yy}	$\frac{1}{YY'}$	$\frac{1}{Y^2} (\frac{1}{Y'^2})$	$\frac{1}{YY'}$	$\frac{1}{Y^2}$
F_{xy}	$F^*_{xy}\sqrt{F_{xx}F_{yy}}$	$F^*_{xy}\sqrt{F_{xx}F_{yy}}$	$F^*_{xy}\sqrt{F_{xx}F_{yy}}$	$F^*_{xy}\sqrt{F_{xx}F_{yy}}$
F^*_{xy}	$-1 < F^*_{xy} < 1^{\dagger\dagger}$	Material Property†††	$-\frac{1}{2}\sqrt{\frac{YY'}{XX'}}$	$-\frac{1}{2}\frac{Y}{X}$
F_{ss}	$\frac{1}{S^2}$	$\frac{1}{S^2}$	$\frac{1}{S^2}$	$\frac{1}{S^2}$
F_x	$\frac{1}{X} - \frac{1}{X'}$		$\frac{1}{X} - \frac{1}{X'}$	
F_y	$\frac{1}{Y} - \frac{1}{Y'}$		$\frac{1}{Y} - \frac{1}{Y'}$	

$^{+}$The values within the parenthesis are used when the corresponding stress component is compressive.

$^{++}$In the Tsai-Wu criterion F^*_{xy} is taken to be -1/2.

$^{+++}$In Chamis criterion F^*_{xy} varies from material to material. For T300/5208 $F^*_{xy} = -.7$.

X = Longitudinal tensile strength

X' = Longitudinal compressive strength

Y = Transverse tensile strength

Y' = Transverse compressive strength

S = Longitudinal shear strength

$$F = \begin{bmatrix} F_{xx} & F_{xy} & 0 \\ F_{xy} & F_{yy} & 0 \\ 0 & 0 & F_{ss} \end{bmatrix}, \quad \bar{F} = \begin{bmatrix} F_x \\ F_y \\ 0 \end{bmatrix}, \quad \sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_s \end{bmatrix}$$

A superscript T denotes transpose of the matrix and the subscripts x, y and s denote, respectively, longitudinal, transverse and shear directions, E denotes the Young's modulus of the ply. The quadratic polynomial failure criterion, through the use of the stress strain relations, can be expressed in strain space as follows:

$$\varepsilon^T G \varepsilon + \bar{G}^T \varepsilon = 1 \tag{13a}$$

where the elements of matrix G and vector $\bar{G}^T$ are dependent upon the ply modulus matrix Q_{ij}, and F_{ij} and $\bar{F}_i$ of Table 8 and

$$\varepsilon = \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_s \end{bmatrix}$$

For the computation of the failure envelopes in the qr space the following definitions are used:

$$p_\varepsilon = (\varepsilon_1 + \varepsilon_2)/2 \qquad p_\sigma = (\sigma_1 + \sigma_2)/2$$

$$q_\varepsilon = (\varepsilon_1 - \varepsilon_2)/2 \qquad q_\sigma = (\sigma_1 - \sigma_2)/2$$

$$r_\varepsilon = \varepsilon_6/2 \qquad r_\sigma = \sigma_6$$

where ε_i and σ_i are stress and strain components in the laminate axes.

Chamis, Hoffman and Hill criteria can be deduced from Tsai-Wu failure criterion by using different values of F^*_{xy} and appropriate X, X', Y and Y' as given in Table 8.

According to the quadratic polynomial failure criterion the failure surface in strain space, equation 13a, is represented by the following quadratic equation:

$$G_{ij}\varepsilon_i\varepsilon_j + G_i\varepsilon_i = 1 \qquad (i,j = x,y,s) \tag{13}$$

where nonzero coefficients G_{ij} in the foregoing equation are given by

$$
\begin{aligned}
G_{xx} &= F_{xx}Q_{xx}^2 + 2F_{xy}Q_{xx}Q_{xy} + F_{yy}Q_{xy}^2 \\
G_{yy} &= F_{xx}Q_{xy}^2 + 2F_{xy}Q_{xy}Q_{yy} + F_{yy}Q_{yy}^2 \\
G_{xy} &= F_{xx}Q_{xx}Q_{xy} + F_{xy}[Q_{xx}Q_{yy} + Q_{xy}^2] + F_{yy}Q_{xy}Q_{yy} \\
G_{ss} &= F_{ss}Q_{ss}^2 = (Q_{ss}/S)^2 \\
G_x &= F_xQ_{xx} + F_yQ_{xy} \\
G_y &= F_xQ_{xy} + F_yQ_{yy}
\end{aligned} \tag{14}
$$

Subroutine FAILCO computes the coefficients G_{ij} and G_i in Equation 13. Equation 13 can be written in the following expanded form:

$$
\begin{aligned}
&G_{xx}\varepsilon_x^2 + 2G_{xy}\varepsilon_x\varepsilon_y + G_{yy}\varepsilon_y^2 + G_{ss}\varepsilon_s^2 \\
&+ G_x\varepsilon_x + G_y\varepsilon_y = 1
\end{aligned} \tag{15}
$$

With the knowledge of applied stress or strain, the above relation will enable the designer to predict if the structure is going to survive or fail. This relation becomes easier to use if we introduce a strength ratio parameter R defined by:

$$
\varepsilon^M_{allowed} = R\,\varepsilon^M_{imposed} \tag{16}
$$

Here, the superscript M denotes the mechanical strain. The strains that must satisfy the failure criterion are:

$$
\varepsilon_i]_{allowed} = \varepsilon^M_i]_{allowed} + \varepsilon^N_i - e_i
$$

$$
= \begin{matrix}
\varepsilon^M_x + \varepsilon^N_x - e_x \\
\varepsilon^M_y + \varepsilon^N_y - e_y \\
\varepsilon^M_s + \varepsilon^N_s
\end{matrix} \tag{17}
$$

The superscript N denotes nonmechanical strain, e_x and e_y are longitudinal and transverse strain components in the ply axis. Using Equations 16 and 17, Equation 15 is given in the following form:

$$G_{ij} (R\,\varepsilon_i^M + \varepsilon_i^N - e_i)(R\varepsilon_j^M + \varepsilon_j^N - e_j)$$

$$+ G_i (R\,\varepsilon_i^M + \varepsilon_i^N - e_i) = 1 \qquad (18)$$

With algebraic rearrangements this equation reduces to:

$$aR^2 + bR + c = 0 \qquad (19)$$

where a, b and c are coefficients of R^2, R and 1 in Equation 18 and are dependent upon the material properties of the laminate and applied loadings. The roots of this equation give the strength ratios R and R^{-}, where R^{-} denotes the reversed load strength ratio.

Subroutine FSFTY computes the strength ratios R and R^{-}. However, in the print output only R has been given. A parameter R/h that corresponds to the strength of the ply (in case of a unit applied stress resultant N_i, i=1,2,6) has also been given in the print output. Since on variation of ply number or orientation in a laminate the total laminate thickness may vary, thus the introduction of R/h will be helpful in understanding the strength of different laminates.

For Chamis' criterion, when nonmechanical loads are included, the signs of mechanical stress components govern the choice of F_{xx} and F_{yy} of table 8. This can be changed to incorporate the resultant ply strains in subroutines FSFTY and STRNG.

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5. C. C. Chamis, "Failure Criteria for Filamentary Composites", Composite Materials: Testing and Design, ASTM STP 460, ASTM, 1970, p. 336.

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9. S. R. Soni, "A Comparative Study of Failure Envelopes in Composite Laminates", to appear in J. Reinforced Plastics and Composites, Jan. 1983.

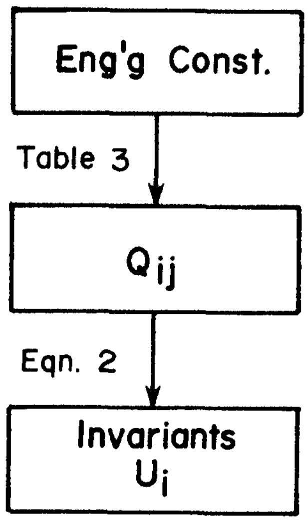
10. S. R. Soni, "Design Analysis of Thick Composites", Proceedings of 28th National SAMPE Symposium held at Anahiem, California, April 12-14, 1983.

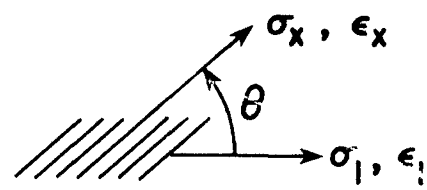
11. S. R. Soni, "A New Look at Commonly Used Failure Theories in Layered Composites", 24th SDM/AIAA/ASME/ASCE/AHS, Lake Tahoe Meeting Proceedings, May 2-4, 1983, pp. 171-179.

12. S. R. Soni, "A Digital Algorithm for Composite Laminate Analysis-Fortran", Air Force Wright Aeronautical Laboratories, Materials Laboratory Technical Report, AFWAL-TR-81-4073, 1981.

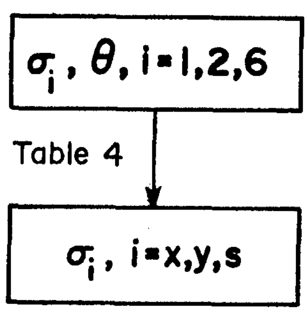
FLOW DIAGRAMS FOR DIFFERENT SUBROUTINES

Subroutine MODULS: Calculates ply on axis modulus

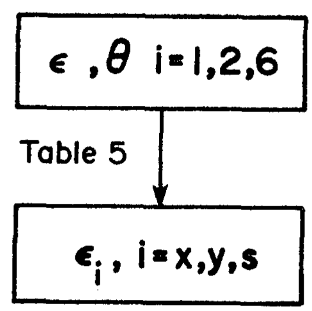




Subroutine TRS:
Stress transformation

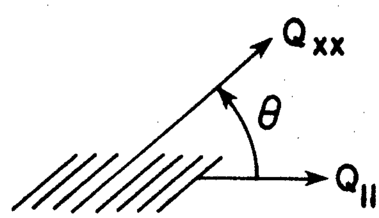


Subroutine TRE:
Strain transformation



Subroutine MODCM: Ply off axis modulus

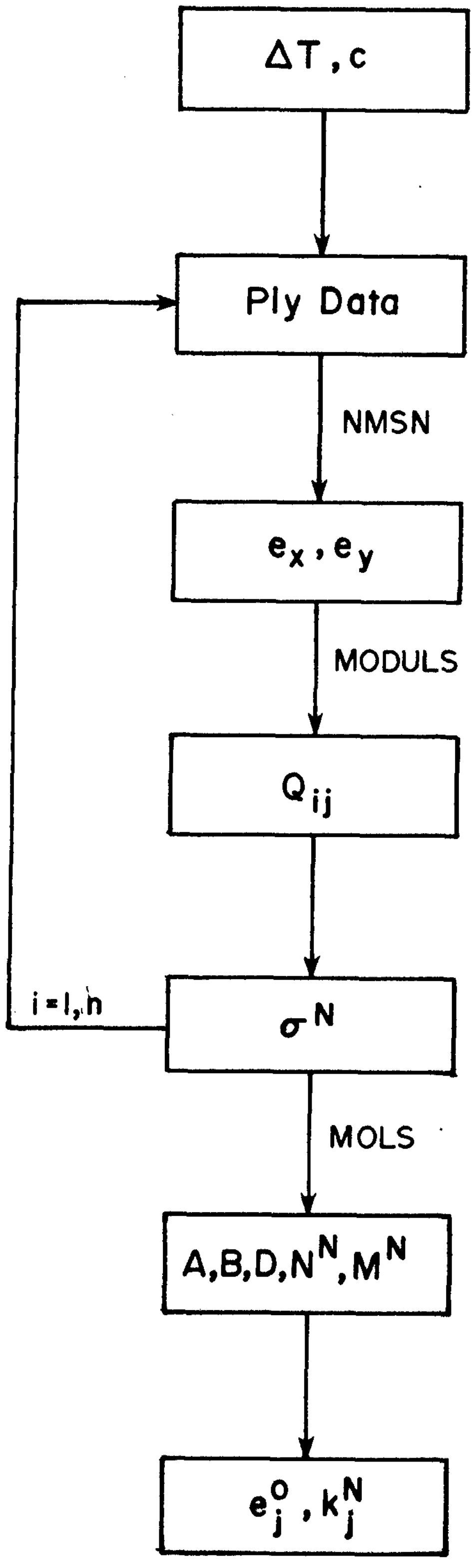
$$
\begin{tikzcd}
\boxed{\text{Eng'g Const. } \theta} \arrow[d, "\text{MODULS}"'] \\
\boxed{U_i} \arrow[d, "\text{Table 7}"'] \\
\boxed{Q_{ij}\ (\theta)}
\end{tikzcd}
$$

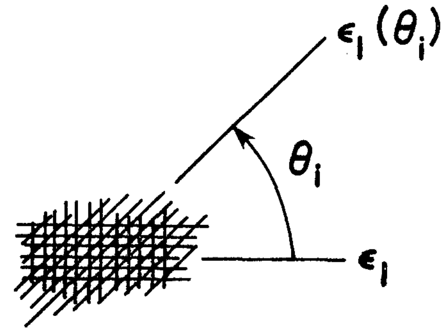


Subroutine NMSN: Ply nonmechanical strain

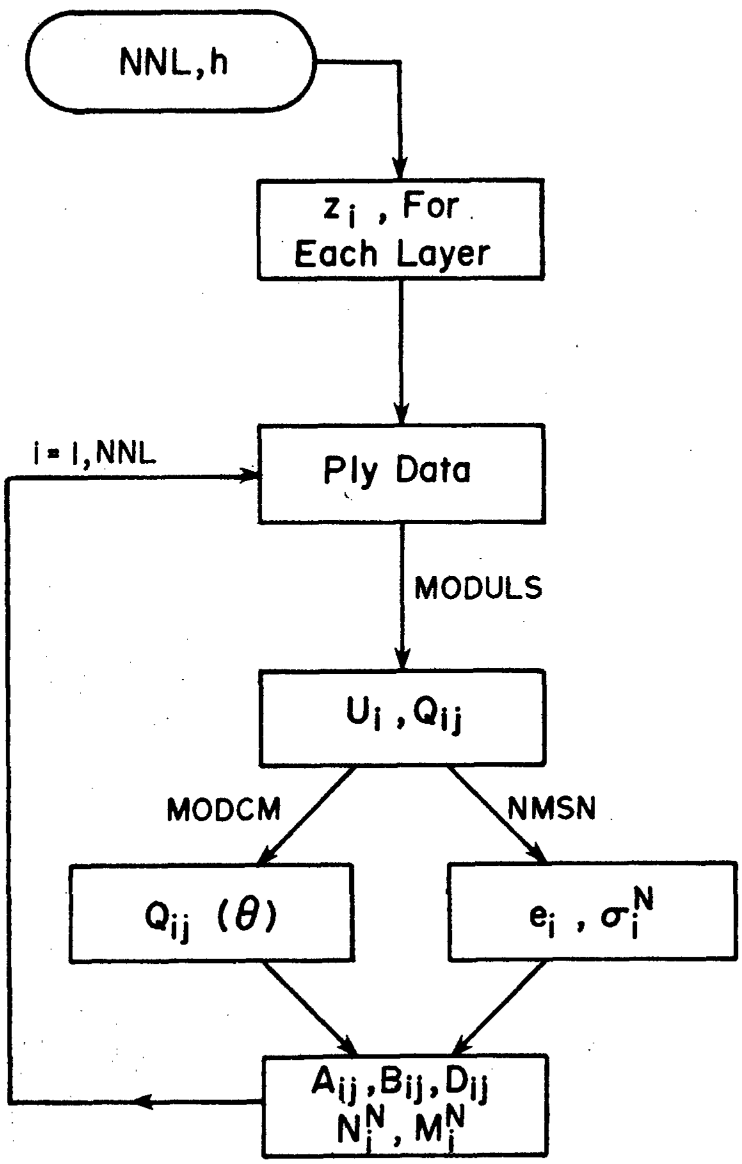
$$
\begin{tikzcd}
\boxed{\Delta T, c} \arrow[d] \\
\boxed{\alpha_i, \beta_i} \arrow[d, "\text{Eqn. 7}"'] \\
\boxed{e_x, e_y}
\end{tikzcd}
$$

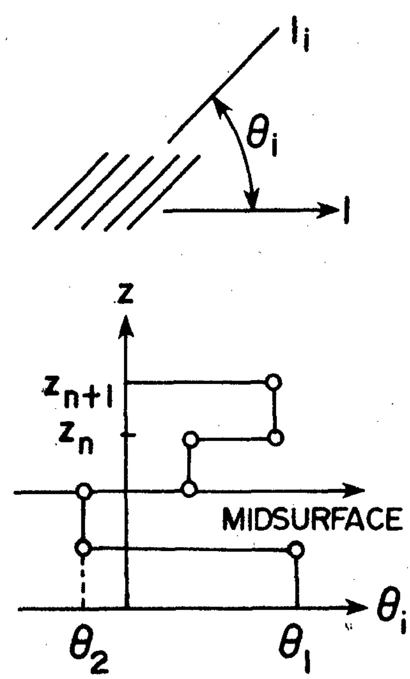
Flow Chart for inplane nonmechanical strain





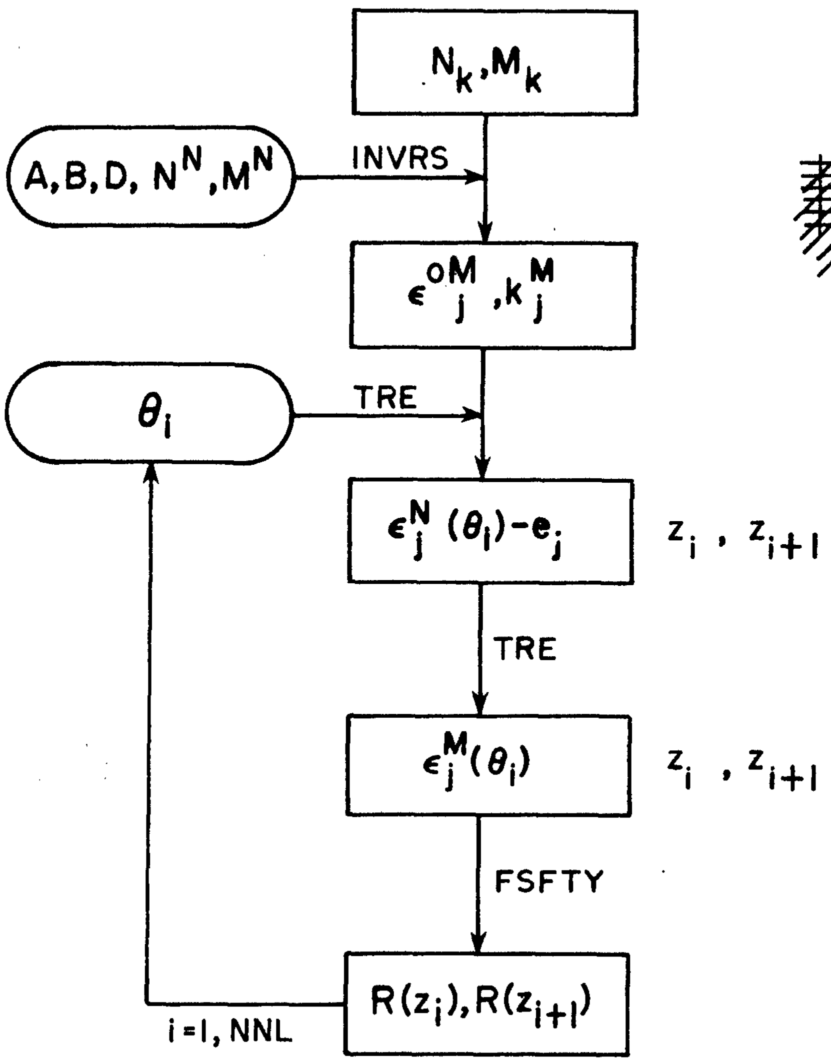
Subroutine MOLS: Effective modulus and nonmechanical loads

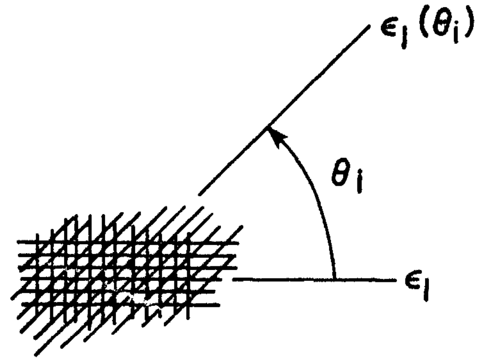




NNL = Number of layers in the laminate.
= n

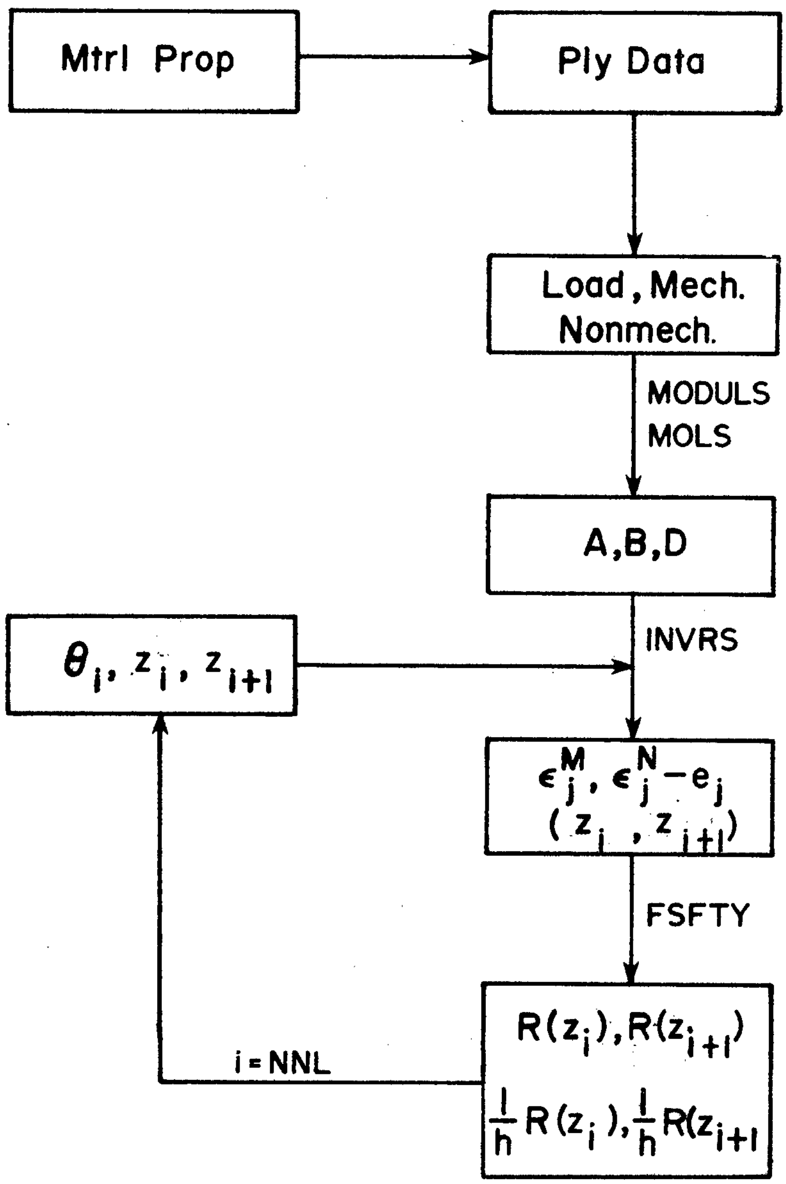
Flow chart for each ply strength in general laminates.





NNL = n

Program Main



APPENDIX A

```
      INTEGER TITL(4),CASE,PARAM,PARAM1,PARAM2,PARAM3,MATRIAL,UNITS
      DIMENSION PLNM(40),T(3)
      DIMENSION ZERO(3,3),DUM(3,3),DUM1(3,3)
      DIMENSION U(5),DU7(3,3),HS(41),AN(3),AM(3)
      DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),DU5(3,3)
      DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
      DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
      DIMENSION SB3(3,3),HLC(40),HT(40),TL(40),TT(40),P(3),SH(8)
      DIMENSION EX(8),EY(8),VX(8),ES(8)   ,ALFX(8),ALFY(8),BTAX(8)
      DIMENSION BTAY(8),X(8), XD(8),Y(8), YD(8),S(8),LMPI(40)
      DIMENSION Q(3,3),A(3,3),HL(40),TH(40),SFL(40),QQ(3)
      DIMENSION NAMES(17)
      DIMENSION NEWN(3)
      COMMON /SF/SFL,COUNT
      COMMON /BLH/ H,HI
      COMMON /BLM/ PARAM2,PARAM3
      COMMON/BLK/HLC,HT,TL,TT
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON /UNIT/ IUNIT
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON /TIT/ TITL
      COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
      COMMON /MPIL/ LMPI
      COMMON /BLDU/ DU2,DU4,DU5,DU7
      NAMELIST /LAMDATA/NNM,EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,
     *SH
      NAMELIST/LAYERS/NNL,LMPI,TH,PLNM,IUNIT,DT,C,NLDCN
      NAMELIST/LAYER/NNL,TH,PLNM,DT,C,NLDCN
      NAMELIST /STRESS/ AN,AM
      DATA NAMES/7HINITIAL,6HTHEEND,9HTRANSFORM,6HSTRESS,6HSTRAIN,
     *7HMODULUS,10HCOMPLIANCE,6HMODCOM,8HLAMINATE,7HINPLANE,4HPURE,
     *6HHYBRID,7HGENERAL,8HSTRENGTH,4H    ,10HSTRNGTHPLT,7HENGCPLT/
      DATA NEWN/8HNEWMTRLS,2HSI,7HENGLISH/
C
C     *****************************************************************
C     *
C     *
C     *
C     *                  A COMPOSITE LAMINATE ANALYSIS PROGRAM
C     *
C     *                             DEVELOPED BY
C     *
C     *                             SOM R. SONI
C     *                        UNIVERSITY OF DAYTON
C     *                         RESEARCH INSTITUTE
C     *                          300 COLLEGE PK.
C     *                         DAYTON OHIO 45469
C     *                       TEL. # (513) 255- 6809
C     *
C     *****************************************************************
C
C
13    FORMAT(5X,*-----------------------------------------------------------
     *--------*)
      WRITE 13
      WRITE 1001
      WRITE 13
```

```
      WRITE 1003
      WRITE 13
1001  FORMAT(5X,*A COMPOSITTE LAMINATE ANALYSIS PROGRAM*)
      CALL LMDT
1002  FORMAT(5X,*DEVELOPED BY*,/,
     15X,*SOM  R.  SONI*,/,
     25X,*UNIVERSITY OF DAYTON RESEARCH INSTITUTE*,/,
     35X,*DAYTON OHIO 45469*,/,
     45X,*FOR QUESTIONS CALL  513-255-6809*,/)
1003  FORMAT(5X,*MATERIAL PROPERTY DATA*)
      WRITE 13
      DO 303 I=1,3
      DO 303 J=1,3
      ZERO(I,J)=0.
303   CONTINUE
706   FORMAT(7F10.3)
799   CONTINUE
      IUNIT=2
      WRITE 711
711   FORMAT(1H1)
      READ 700,(TITL(I),I=1,4)
      IF(TITL(1) .EQ. NAMES(2)) STOP
      IF(TITL(1) .EQ. NEWN(1)) READ LAMDATA
      IF(TITL(1) .EQ. NEWN(1)) GO TO 799
      PRINT LAMDATA
700   FORMAT(6A10)
      IF(TITL(1) .EQ. NAMES(2)) GO TO 902
      IF(TITL(1) .EQ. NAMES(9) .AND. TITL(2) .EQ. NAMES(10)) GO TO 722
      IF(TITL(1) .EQ. NAMES(9) .AND. TITL(2) .EQ. NAMES(13)) GO TO 723
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(4)) GO TO 724
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(5)) GO TO 725
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(6)) GO TO 726
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(7)) GO TO 726
      IF(TITL(1) .EQ. NAMES(3) .AND. TITL(2) .EQ. NAMES(8)) GO TO 726
724   CONTINUE
      READ 701, (AN(I),I=1,3), THETA
701   FORMAT(4F10.3)
      WRITE 702,THETA
702   FORMAT(5X,*STRESS TRANSFORMATION THRU  *,F7.2,2X,*DEGREES*,/,10X,
     .*              SIGMA1    SIGMA2    SIGMA6*)
      WRITE 13
      WRITE 703, (AN(I),I=1,3)
703   FORMAT (5X,*GIVEN          *,3F10.3)
      CALL TRS(AN,T,THETA)
      WRITE 704,(T(I),I=1,3)
704   FORMAT(5X,*TRANSFORMED    *,3F10.3)
      WRITE 13
      GO TO 799
725   CONTINUE
      READ 701, (AN(I),I=1,3), THETA
      WRITE 705,THETA
705   FORMAT(5X,*STRAIN TRANSFORMATION THRU  *,F7.2,2X,*DEGREES*,/,10X,
     .*              EPSLN1    EPSLN2    EPSLN6*)
      WRITE 13
      WRITE 703, (AN(I),I=1,3)
      CALL TRE(AN,T,THETA)
      WRITE 704,(T(I),I=1,3)
      WRITE 13
```

```
      GO TO 799
726   CONTINUE
      READ 700,MATRIAL,UNITS
      IF(UNITS .NE. NEWN(3)) IUNIT=1
      CALL MINP(MATRIAL,LI)
      IF(LI .EQ. 8) READ 706,EX(LI),EY(LI),VX(LI),ES(LI),TH(1)
      IF(LI .LT. 8) READ 706,TH(1)
      NNL=1
      LMPI(1)=LI
      PLNM(1)=1.
      CALL MTDM(PLNM,PM,GM,PMI,TPI)
      CALL MODULS(ES11(1),ES22(1),VS12(1),GS12(1),Q,U)
      CALL MODCM(TH(1),U,SB1)
      CALL MTAD(ZERO, SB1,SB2,PMI)
      CALL MTAD(ZERO,Q,SB3,PMI)
      IF(TITL(2) .EQ. NAMES(7)) GO TO 727
      WRITE 707,TH(1)
707   FORMAT(5X,*MODULUS TRANSFORMATION THRU  *,F7.2,*  DEGREE ANGLE*)
      IF(IUNIT .NE. 1) WRITE 713
      IF(IUNIT .EQ. 1) WRITE 712
712   FORMAT(30X,*(GPA)*)
713   FORMAT(30X,*(1.E+06 PSI)*)
      WRITE 13
      WRITE 709
709   FORMAT(5X,*MODULUS OF THE MATERIAL*,10X,*TRANSFORMED MODULUS*)
      WRITE 13
      CALL WITE1(SB3,SB2)
      WRITE 13
      IF(TITL(2) .EQ. NAMES(6)) GO TO 799
727   CONTINUE
      CALL INVRS(SB3,DUM)
      CALL INVRS(SB2,DUM1)
      CALL MTAD(ZERO,DUM,DU1,1000.)
      CALL MTAD(ZERO,DUM1,DU2,1000.)
      WRITE 708, TH(1)
708   FORMAT(5X,*COMPLIANCE TRANSFORMATION THRU  *,F7.2,*  DEGREE ANGLE*
     .)
      IF(IUNIT .EQ. 1) WRITE 714
      IF(IUNIT .NE. 1) WRITE 715
714   FORMAT(30X,*(1/TPA)*)
715   FORMAT(30X,*(1.0E-09/PSI)*)
      WRITE 13
      WRITE 710
710   FORMAT(5X,*COMPLIANCE OF MATERIAL*,13X,*TRANSFORMED COMPLIANCE*)
      WRITE 13
      CALL WITE1(DU1,DU2)
      WRITE 13
      GO TO 799
722   READ 700,CASE,PARAM,PARAM1,PARAM2,PARAM3
      TITL(4)=CASE
      IF(CASE .EQ. NAMES(12)) GO TO 731
      IF(CASE .NE. NAMES(11)) STOP "ERROR IN MIND"
      CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
      CALL MTDM(PLNM,PM,GM,PMI,TPI)
      CALL MOLS(TH,HL,HS)
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      CALL MTAD(ZERO,SB1,DUM1,HI)
      CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
      CALL NORM1(TPI,A,PARAM1)
```

```
      IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
      GO TO 799
  731 CONTINUE
      CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
      CALL MTDM(PLNM,PM,GM,PMI,TPI)
      CALL MOLS(TH,HL,HS)
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      CALL MTAD(ZERO,SB1,DUM1,HI)
      CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
      CALL NORM1(TPI,A,PARAM1)
      IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
      IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
      IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
      GO TO 799
  723 READ 700,CASE,PARAM,PARAM1,PARAM2
      TITL(4)=CASE
      IF(CASE .EQ. NAMES(12)) GO TO 732
      IF(CASE .NE. NAMES(11)) STOP "ERROR IN MIND"
      CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
      CALL MTDM(PLNM,PM,GM,PMI,TPI)
      CALL MOLS(TH,HL,HS)
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      CALL MTAD(ZERO,SB1,DUM1,HI)
      CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
      CALL NORM1(TPI,A,PARAM1)
      IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
      IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
      IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
      GO TO 799
  732 CONTINUE
      CALL LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
      CALL MTDM(PLNM,PM,GM,PMI,TPI)
      CALL MOLS(TH,HL,HS)
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      CALL MTAD(ZERO,SB1,DUM1,HI)
      CALL NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PARAM)
      CALL NORM1(TPI,A,PARAM1)
      IF(PARAM2 .EQ. NAMES(14)) CALL STRNG(TH,HS,PM,NLDCN)
      IF(PARAM2 .EQ. NAMES(16)) CALL STPLT(TH,HS,PM,PLNM)
      IF(PARAM3 .EQ. NAMES(17)) CALL PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
      GO TO 799
  902 CONTINUE
      WRITE 13
      STOP
      END
```

```
      SUBROUTINE ADJUST(ICND,SFLN,SPLC,AN)
      INTEGER CRITRIA,SPACE,PLANE
      DIMENSION STX1(200),STY1(200),SCX1(200),SCY1(200)
      DIMENSION STX2(200),STY2(200),SCX2(200),SCY2(200)
      DIMENSION STX3(200),STY3(200),SCX3(200),SCY3(200)
      DIMENSION SFLN(40),SPLC(40),AN(3),NAME(2)
      COMMON /ST1/ STX1,STY1,SCX1,SCY1,NSF1
      COMMON /ST2/ STX2,STY2,SCX2,SCY2,NSF2
      COMMON /ST3/ STX3,STY3,SCX3,SCY3,NSF3
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      DATA NAME/2HQR,6HSTRESS/
      IF(PLANE .EQ. NAME(1)) GO TO 1
      STX1(ICND)=SFLN(NSF1)*AN(1)
      STY1(ICND)=SFLN(NSF1)*AN(2)
      SCX1(ICND)=SPLC(NSF1)*AN(1)
      SCY1(ICND)=SPLC(NSF1)*AN(2)
      STX2(ICND)=SFLN(NSF2)*AN(1)
      STY2(ICND)=SFLN(NSF2)*AN(2)
      SCX2(ICND)=SPLC(NSF2)*AN(1)
      SCY2(ICND)=SPLC(NSF2)*AN(2)
      STX3(ICND)=SFLN(NSF3)*AN(1)
      STY3(ICND)=SFLN(NSF3)*AN(2)
      SCX3(ICND)=SPLC(NSF3)*AN(1)
      SCY3(ICND)=SPLC(NSF3)*AN(2)
      RETURN
1     CONTINUE
      SQ2=SQRT(2.0)
      SQ3=SQ2
      IF(SPACE .EQ. NAME(2)) SQ3=1./SQ2
      STX1(ICND)=SQ2*SFLN(NSF1)*AN(1)
      STX2(ICND)=SQ2*SFLN(NSF2)*AN(1)
      STX3(ICND)=SQ2*SFLN(NSF3)*AN(1)
      SCX1(ICND)=SQ2*SPLC(NSF1)*AN(1)
      SCX2(ICND)=SQ2*SPLC(NSF2)*AN(1)
      SCX3(ICND)=SQ2*SPLC(NSF3)*AN(1)
      STY1(ICND)=SFLN(NSF1)*AN(3)/SQ3
      STY2(ICND)=SFLN(NSF2)*AN(3)/SQ3
      STY3(ICND)=SFLN(NSF3)*AN(3)/SQ3
      SCY1(ICND)=SPLC(NSF1)*AN(3)/SQ3
      SCY2(ICND)=SPLC(NSF2)*AN(3)/SQ3
      SCY3(ICND)=SPLC(NSF3)*AN(3)/SQ3
      RETURN
      END
```

```
      SUBROUTINE AMAX(XX,NN,AMX)
      DIMENSION XX(10)
      AMX=XX(1)
      DO 1 I=1,NN
      IF(XX(I) .GE. AMX) AMX=XX(I)
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AMIN(XX,NN,AMN,IK)
      DIMENSION XX(20)
      AMN=XX(1)
      DO 1 I=1,NN
      IF(XX(I) .LE. AMN) GO TO 2
      GO TO 1
2     AMN=XX(I)
      IK=I
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COEF(G,GB,GS,GSB,THET)
      DIMENSION G(3,3),GB(3),GS(3,3),GSB(3),U(5)
      CALL US(G,U)
      CALL MODCM(THET,U,GS)
      H1=(GB(1)+GB(2))/2.
      H2=(GB(1)-GB(2))/2.
      TH2=2.*THET
      C=COSM(TH2)
      S=SINM(TH2)
      GSB(1)=H1+H2*C
      GSB(2)=H1-H2*C
      GSB(3)=H2*S
      RETURN
      END
```

```
      SUBROUTINE FAILCO(E,Q,X,XD,Y,YD,XLT,G,GB)
      INTEGER CRITRIA,SPACE,PLANE
      DIMENSION E(3),E1(3)
      DIMENSION Q(3,3),G(3,3),F(3,3),GB(3),FB(3),C(3,3)
      DIMENSION NAME(6)
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      DATA NAME /7HTSAI WU,7HHOFFMAN,4HHILL,6HCHAMIS,6HSTRAIN,6HSTRESS/
      XL=X
      XC=XD
      YL=Y
      YC=YD
      IF(CRITRIA .EQ. NAME(1) .OR. CRITRIA .EQ. NAME(2)) GO TO 1
      IF(CRITRIA .EQ. NAME(4)) GO TO 2
      XC=X
      YC=Y
      GO TO 1
2     CALL MVM(Q,E,E1)
      IF(E1(1) .LT.0.) XL=XD
      IF(E1(1) .GT.0.) XC=X
      IF(E1(2) .LT.0.) YL=YD
      IF(E1(2) .GT.0.) YC=Y
1     CONTINUE
      F(1,1)=1.0/(XL*XC)
      F(2,2)=1.0/(YL*YC)
C     F(1,2)=0.
      COE=SQRT(F(1,1)*F(2,2))
      F(1,2)=FS12*COE
      IF(CRITRIA.EQ. NAME(2) .OR.CRITRIA .EQ. NAME(3)) F(1,2)=-.5*F(1,1)
      IF(CRITRIA .EQ. NAME(4)) F(1,2)=FS12*COE
      F(3,3)=1.0/(XLT*XLT)
      FB(1)=(XC-XL)*F(1,1)
      FB(2)=(YC-YL)*F(2,2)
      FB(3)=0.0
      F(2,1)=F(1,2)
      F(3,1)=0.0
      F(3,2)=0.0
      F(1,3)=0.0
      F(2,3)=0.0
      CALL MATM(Q,F,C)
      CALL MATM(C,Q,G)
      CALL MVM(Q,FB,GB)
      RETURN
      END


      SUBROUTINE FSFTY(ET,EN,G,GB,SM,SMN)
      DIMENSION ET(3),EN(3),G(3,3),GB(3),TS(3),T(3)
      CALL MVM(G,ET,T)
      CALL MVM(G,EN,TS)
      AC=VVM(T,ET)
      BC= VVM(T,EN)+VVM(TS,ET)+VVM(ET,GB)
      CC=VVM(EN,TS)+VVM(GB,EN)-1.0
      CALL ROOTS(AC,BC,CC,SM,SMN)
      RETURN
      END
```

```
      SUBROUTINE INVRS(Q,A)
      DIMENSION Q(3,3),A(3,3)
      DET=Q(1,1)*Q(2,2)*Q(3,3)+2.0*Q(1,2)*Q(1,3)*Q(2,3)-Q(2,2)*Q(1,3)**2
     *-Q(1,1)*Q(2,3)**2-Q(3,3)*Q(1,2)**2
      A(1,1)=(Q(2,2)*Q(3,3)-Q(2,3)**2)/DET
      A(3,3)=(Q(1,1)*Q(2,2)-Q(1,2)**2)/DET
      A(2,2)=(Q(1,1)*Q(3,3)-Q(1,3)**2)/DET
      A(1,3)=(Q(1,2)*Q(2,3)-Q(2,2)*Q(1,3))/DET
      A(1,2)=(Q(1,3)*Q(2,3)-Q(1,2)*Q(3,3))/DET
      A(2,3)=(Q(1,2)*Q(1,3)-Q(1,1)*Q(2,3))/DET
      DO 1 I=1,3
      DO 1 J=1,3
      A(J,I)=A(I,J)
 1    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LMDT
      DIMENSION EX(8),EY(8),VX(8),ES(8)   ,ALFX(8),ALFY(8),BTAX(8)
      DIMENSION BTAY(8),X(8), XD(8),Y(8), YD(8),S(8),SH(8)
      COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
C     DATA EX/145.,204.,138.,38.6,76.,0.,69.,0./
      DATA EX/181.,204.,138.,38.6,76.,0.,69.,0./
C     DATA EY/11.0,18.5,8.96,8.27,5.5,0.,69.,0./
      DATA EY/10.3,18.5,8.96,8.27,5.5,0.,69.,0./
C     DATA VX/.25,.23,.3,.26,.34,0.,.3,0./
      DATA VX/.28,.23,.3,.26,.34,0.,.3,0./
C     DATA ES/5.50,5.59,7.1,4.14,2.3,0.,26.5,0./
      DATA ES/7.17,5.59,7.1,4.14,2.3,0.,26.5,0./
      DATA ALFX/.02,6.1,-.3,8.6,-4.0,.0,0.,0./
      DATA ALFY/22.5,30.3,28.1,22.1,79.0,.0,12.5,0./
      DATA BTAX/0.,0.,0.,0.,0.,0.,0.,0./
      DATA BTAY/0.6,0.6,.44,.6,.6,.0,0.,0./
C     DATA X/1448.,1260.,1447.,1062.,1400.,.0,400.,0./
      DATA X/1500.,1260.,1447.,1062.,1400.,.0,400.,0./
C     DATA XD/1448.,2500.,1447.,610.,235.,.0,400.,0./
      DATA XD/1500.,2500.,1447.,610.,235.,.0,400.,0./
C     DATA Y/52.,61.,51.7,31.,12.,0.,400.,0./
      DATA Y/40.,61.,51.7,31.,12.,0.,400.,0./
C     DATA YD/207.,202.,206.,118.,53.,0.,400.,0./
      DATA YD/246.,202.,206.,118.,53.,0.,400.,0./
C     DATA S/93.0,67.,93.,72.,34.,0.,230.,0./
      DATA S/68.0,67.,93.,72.,34.,0.,230.,0./
      DATA SH/.125E-03,.125E-03,.125E-03,.125E-03,.125E-03,.001,1.,0./
      DATA NNM/7/
      RETURN
      END
```

```
      SUBROUTINE LMNT(NNL,NLDCN,TH,LMPI,DT,C,PLNM)
      INTEGER TITL(4),MATRIAL,UNITS
      DIMENSION TH(40),NAMES(4),PLNM(40),LMPI(40),DESCRP(8)
      COMMON /UNIT/ IUNIT
      COMMON /TIT/ TITL
      NAMELIST/LAYERS/NNL,LMPI,TH,PLNM,IUNIT,DT,C,NLDCN
      NAMELIST/LAYER/NNL,TH,PLNM,DT,C,NLDCN
      DATA NAMES /4HPURE,6HHYBRID,2HSI,7HENGLISH/
444   FORMAT(8A10)
      WRITE 13
445   FORMAT(1H0,8A10)
      WRITE 13
      READ 444,DESCRP
      PRINT445,DESCRP
      WRITE 13
      IF (TITL(4) .EQ. NAMES(1)) GO TO 609
      READ LAYERS
      GO TO 610
609   READ 700,MATRIAL,UNITS
      IF(UNITS .NE. NAMES(4)) IUNIT=1
      READ LAYER
700   FORMAT(2A10)
      CALL MINP(MATRIAL,LI)
      DO 711 IM=1,NNL
      LMPI(IM)=LI
711   CONTINUE
610   CONTINUE
      WRITE 604,NNL
604   FORMAT(6X,*NUMBER OF PLYS =*,I3)
      WRITE 605
605   FORMAT(6X,*ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1*)
      WRITE 6051,(TH(I),I=1,NNL)
6051  FORMAT(6X,12F5.1)
      WRITE 665
665   FORMAT(6X,*NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION*)
      WRITE 6051,(PLNM(I),I=1,NNL)
      WRITE 607
607   FORMAT(6X,*MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY*)
      WRITE 6071,(LMPI(I),I=1,NNL)
6071  FORMAT(6X,12I5)
      WRITE 608,DT,C
608   FORMAT(6X,*TEMPERATURE DT=*,F10.4,*    MOISTURE=*,F10.4)
13    FORMAT(5X,*-----------------------------------------------------------
     *--------*)
      RETURN
      END
```

```
      SUBROUTINE MATM(A,B,C)
      DIMENSION A(3,3),B(3,3),C(3,3)
      DO 2 I=1,3
      DO 2 J=1,3
      SUM=0.0
      DO 1 K=1,3
      SUM=SUM+A(J,K)*B(K,I)
1     CONTINUE
      C(J,I)=SUM
2     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MINP(MAT,LI)
      DIMENSION NAMES(8)
      DATA NAMES/9HT300/5208,7HB4/5505,7HAS/3501,9HSCOTCHPLY,8HKEVLAR49,
     *4HCORE,8HALUMINUM,3HNEW/
      DO 1 I=1,8
1      IF(MAT .EQ. NAMES(I)) GO TO 2
      STOP "ERROR IN MIND"
2      LI=I
      RETURN
      END
```

```
      SUBROUTINE MODCM(TH,U,Q)
      DIMENSION U(5)
      DIMENSION Q(3,3)
      TH2=2.*TH
      C2=COSM(TH2)
      S2=SINM(TH2)
      TH4=4.*TH
      C4=COSM(TH4)
      S4=SINM(TH4)
      Q(1,1)=U(1)+U(2)*C2+U(3)*C4
      Q(2,2)=U(1)-U(2)*C2+U(3)*C4
      Q(1,2)=U(4)-U(3)*C4
      Q(3,3)=U(5)-U(3)*C4
      Q(1,3)=U(2)*S2/2.+U(3)*S4
      Q(2,3)=U(2)*S2/2.-U(3)*S4
      CALL SYM(Q)
      RETURN
      END
```

```
      SUBROUTINE MODULS(EL,ET,VLT,GLT,Q,U)
      DIMENSION U(5)
      DIMENSION Q(3,3)
      DO 1 I=1,3
      DO 1 J=1,3
      Q(I,J)=0.
1     CONTINUE
      IF (EL.EQ. 0.) GO TO 2
      AM=1./(1.0-VLT*VLT*ET/EL)
      Q(1,1)=EL*AM
      Q(1,2)=AM*ET*VLT
      Q(2,1)=Q(1,2)
      Q(2,2)=AM*ET
      Q(3,3)=GLT
2     CONTINUE
      CALL US(Q,U)
      RETURN
      END
```

```
      SUBROUTINE MOLS(THETA,HL,HN)
      DIMENSION E(3),E1(3),P(3),QQ(3),F(3),ES11(40),ES22(40),GS12(40)
      DIMENSION VS12(40),SB1(3,3),SB2(3,3),SB3(3,3),HL(40),HN(41),Q(3,3)
      DIMENSION THETA(40),HLC(40),HT(40),TL(40),TT(40)
      DIMENSION U(5),QX(3,3)
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON/BLK/HLC,HT,TL,TT
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON /BLH/ H,HI
      TH1=0.
      DO 1 I=1,NNL
      TH1=TH1+HL(I)
1     CONTINUE
      HTT=TH1/2.
      HH=TH1*TH1
      NN=NNL+1
      HN(1)=-HTT
      DO 2 J=2,NN
      HN(J)=HN(J-1)+HL(J-1)
2     CONTINUE
      DO 66 I=1,3
      P(I)=0.
      QQ(I)=0.
      DO 66 J=1,3
      SB2(I,J)=0.
      SB3(I,J)=0.
66    CONTINUE
      DO 6 NL=1,NNL
      H1=HN(NL+1)-HN(NL)
      H2=H1*(HN(NL+1)+HN(NL))/2.
      G=HN(NL+1)*HN(NL)
      H3=H1*(H1*H1+3.*G)/3.
      THT=THETA(NL)
      CALL MODULS(ES11(NL),ES22(NL),VS12(NL),GS12(NL),QX,U)
      CALL MODCM(THT,U,Q)
      CALL NMSN(C,DT,E,HLC,HT,TL,TT,NL)
      CALL MVM(QX,E,E1)
      CALL TRS(E1,F,-THT)
      DO 4 I=1,3
      DO 3 J=I,3
      SB1(I,J)=SB1(I,J)+Q(I,J)*H1
      SB2(I,J)=SB2(I,J)+Q(I,J)*H2
      SB3(I,J)=SB3(I,J)+Q(I,J)*H3
3     CONTINUE
      P(I)=P(I)+F(I)*H1
      QQ(I)=QQ(I)+F(I)*H2
4     CONTINUE
      CALL SYM(SB1)
      CALL SYM(SB2)
      CALL SYM(SB3)
6     CONTINUE
      H=TH1
      HI=1./H
      RETURN
      END
```

```
      SUBROUTINE MTAD(A,B,C,CN)
      DIMENSION A(3,3),B(3,3),C(3,3)
      DO 1 I=1,3
      DO 1 J=1,3
      C(I,J)=A(I,J)+CN*B(I,J)
1     CONTINUE
      RETURN
      END
      SUBROUTINE MTDM(PLNM,PM,GM,PMI,TPI)
      DIMENSION PLNM(40),HL(40)
      DIMENSION ES11(40),ES22(40),VS12(40),GS12(40)
      DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
      DIMENSION HLC(40),HT(40),TL(40),TT(40),SH(8)
      DIMENSION EX(8),EY(8),VX(8),ES(8)   ,ALFX(8),ALFY(8),BTAX(8)
      DIMENSION BTAY(8),X(8), XD(8),Y(8), YD(8),S(8),LMPI(40)
      COMMON /UNIT/ IUNIT
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON/BLK/HLC,HT,TL,TT
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON /DTA/ EX,EY,VX,ES,ALFX,ALFY,BTAX,BTAY,X,XD,Y,YD,S,SH,NNM
      COMMON /MPIL/ LMPI
      CON1=1.0
      CON2=1.0
      PM=1.0E+06
      IF(IUNIT .EQ. 1) GO TO 4455
      PM=PM/6895.
      CON1=5./9.
      CON2=39.4
4455   CONTINUE
      GM=1000.*PM
      DO 1 I=1,NNL
      II=LMPI(I)
      ES11(I)=EX(II)*GM
      ES22(I)=EY(II)*GM
      VS12(I)=VX(II)
      GS12(I)=ES(II)*GM
      TL(I)=ALFX(II)*CON1*1.0E-06
      TT(I)=ALFY(II)*CON1*1.0E-06
      HLC(I)=BTAX(II)
      HT(I)=BTAY(II)
      SXL(I)=X(II)*PM
      SXC(I)=XD(II)*PM
      SYL(I)=Y(II)*PM
      SYC(I)=YD(II)*PM
      SXLT(I)=S(II)*PM
      HL(I)=SH(II)*CON2*PLNM(I)
1     CONTINUE
      IF(IUNIT. NE. 1) PM=1.0E+03
      GM=1000.*PM
      PMI=1./GM
      TPI=1000.*GM
      IF(IUNIT.EQ.1) WRITE 24
      IF(IUNIT.NE.1) WRITE 25
24    FORMAT(20X,*SI UNITS*)
25    FORMAT(20X,*ENGLISH UNITS*)
      RETURN
      END
```

```
      SUBROUTINE MVM(X,Y,Z)
      DIMENSION X(3,3),Y(3),Z(3)
      DO 1 I=1,3
      SUM=0.0
      DO 2 J=1,3
      SUM=SUM+X(I,J)*Y(J)
2     CONTINUE
      Z(I)=SUM
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MXSTRN(K,EN,AAN,Q,PM)
      DIMENSION EPST(3),EPSC(3),SIGR(3),SIGA(3),EN(3),AAN(3),AK(3)
      DIMENSION SXL(40),SXC(40),SYL(40),SYC(40),SXLT(40),A(3,3),Q(3,3)
      DIMENSION HL(40)
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON /BLH/ H,HI
      COMMON /UNIT/ IUNIT
      COMMON /SF/SFL,COUNT
      CALL INVRS(Q,A)
      EPST(1)=SXL(K)*A(1,1)
      EPSC(1)=-SXC(K)*A(1,1)
      EPST(2)=SYL(K)*A(2,2)
      EPSC(2)=-SYC(K)*A(2,2)
      EPST(3)=SXLT(K)*A(3,3)
      EPSC(3)=-SXLT(K)*A(3,3)
      DO 1 I=1,3
      DEN=EPST(I)
      IF(EN(I) .LT. 0.) DEN=EPSC(I)
      AK(I)=EN(I)/DEN
1     CONTINUE
      CALL AMAX(AK,3,AMX)
      DO 2 II=1,3
      SIGR(II)=AAN(II)/AMX
      SIGA(II)=SIGR(II)/H/PM
2     CONTINUE
      SFL=1./(AMX*H*PM)
      IF(COUNT.EQ.1.) RETURN
      WRITE 6,(SIGR(I),I=1,3)
6     FORMAT(5X,*STRESS RESULTANTS*,9X,*N1=*,E8.2,4X,*N2=*,E8.2,4X,
     U*N6=*,E8.2)
      IF(IUNIT .EQ. 1)  WRITE 7,(SIGA(I),I=1,3)
      IF(IUNIT .NE. 1)  WRITE 8,(SIGA(I),I=1,3)
7     FORMAT(5X,*AVERAGE STRESSES MPA   *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
     ,F6.1,2X,*SIGMA6=*,F6.1)
8     FORMAT(5X,*AVERAGE STRESSES KSI   *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
     ,F6.1,2X,*SIGMA6=*,F6.1)
      RETURN
      END
```

```
      SUBROUTINE MXSTRS(K,AN,AAN,PM)
      DIMENSION SIGT(3),SIGC(3),SIGR(3),SIGA(3),AN(3),AAN(3),AK(3)
      DIMENSION SXL(40),SXC(40),SYL(40),SYC(40),SXLT(40)
      DIMENSION HL(40)
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON /BLH/ H,HI
      COMMON /UNIT/ IUNIT
      COMMON /SF/SFL,COUNT
      SIGT(1)=SXL(K)
      SIGT(2)=SYL(K)
      SIGT(3)=SXLT(K)
      SIGC(1)=-SXC(K)
      SIGC(2)=-SYC(K)
      SIGC(3)=-SXLT(K)
      DO 1 I=1,3
      DEN=SIGT(I)
      IF(AN(I) .LT. 0.) DEN=SIGC(I)
      AK(I)=AN(I)/DEN
1     CONTINUE
      CALL AMAX(AK,3,AMX)
      DO 2 II=1,3
      SIGR(II)=AAN(II)/AMX
      SIGA(II)=SIGR(II)/H/PM
2      CONTINUE
      SFL=1./(AMX*H*PM)
      IF(COUNT.EQ.1.) RETURN
      WRITE 6,(SIGR(I),I=1,3)
6     FORMAT(5X,*STRESS RESULTANTS*,9X,*N1=*,E8.2,4X,*N2=*,E8.2,4X,
     U*N6=*,E8.2)
      IF(IUNIT .EQ. 1)  WRITE 7,(SIGA(I),I=1,3)
      IF(IUNIT .NE. 1)  WRITE 8,(SIGA(I),I=1,3)
7     FORMAT(5X,*AVERAGE STRESSES MPA   *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
     ,F6.1,2X,*SIGMA6=*,F6.1)
8     FORMAT(5X,*AVERAGE STRESSES KSI   *,*SIGMA1=*,F6.1,2X,*SIGMA2=*,
     ,F6.1,2X,*SIGMA6=*,F6.1)
      RETURN
      END


      SUBROUTINE NMSN(C,DT,EN1,HL,HT,TL,TT,K)
      DIMENSION EN1(3),HL(40),HT(40),TL(40),TT(40)
      EN1(1)=C*HL(K)+DT*TL(K)
      EN1(2)=C*HT(K)+DT*TT(K)
      EN1(3)=0.
      RETURN
      END
```

```
      SUBROUTINE NORM(PMI,ZERO,DU1,DU2,DU3,DU4,PAR)
      INTEGER PAR
      DIMENSION NAMES(6),A(3,3)
      DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),ZERO(3,3)
      DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),HLC(40),HT(40)
      DIMENSION TL(40),TT(40),DUM(3,3),DUM1(3,3),ECON(4),ECONF(4)
      COMMON /UNIT/ IUNIT
      COMMON /BLH/ H,HI
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON/BLK/HLC,HT,TL,TT
      DATA NAMES /10HDIMENSIONL,10HNORMALIZED,4HBOTH,8HENGCONST,3HALL,
     *4H    /
13    FORMAT(5X,*-----------------------------------------------------
     *--------*)
      HSQ=H*H
      HIS=1./HSQ
      PMN1=PMI/H
      PMN2=2.*PMI/HSQ
      PMN3=12.*PMN1/HSQ
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      ECON(1)=PMI/DUM(1,1)
      ECON(2)=PMI/DUM(2,2)
      ECON(3)=-DUM(1,2)/DUM(1,1)
      ECON(4)=PMI/DUM(3,3)
      CALL INVRS(SB3,DUM1)
      HQTW=HSQ*H/12.
      CALL MTAD(ZERO,DUM1,DUM,HQTW)
      ECONF(1)=PMI/DUM(1,1)
      ECONF(2)=PMI/DUM(2,2)
      ECONF(3)=-DUM(1,2)/DUM(1,1)
      ECONF(4)=PMI/DUM(3,3)
      CALL MTAD(ZERO,SB1,DU1,PMN1)
      CALL MTAD(ZERO,SB2,DU2,PMN2)
      CALL MTAD(ZERO,DU2,DU3,3.)
      CALL MTAD(ZERO,SB3,DU4,PMN3)
      WRITE 13
      IF(PAR .EQ. NAMES(6)) GO TO 725
      IF(PAR .EQ. NAMES(4)) GO TO 724
      IF(PAR .EQ. NAMES(2)) GO TO 723
      WRITE 14
      WRITE 15
14    FORMAT(35X,*A    B*,//)
15    FORMAT(35X,*B    D*)
      WRITE 13
      CALL WITE(SB1,SB2)
      CALL WITE(SB2,SB3)
      WRITE 13
      IF(PAR .EQ. NAMES(1)) GO TO 725
723   CONTINUE
      WRITE 42
42    FORMAT(35X,* A#    B#*,//)
       IF(IUNIT .EQ. 1) WRITE 43
       IF(IUNIT .NE. 1) WRITE 443
```

```
43    FORMAT(35X,*3B#   D#      GPA*)
443   FORMAT(35X,*3B#   D#        1.E+06 PSI*)
      WRITE 13
      CALL WITE1(DU1,DU2)
      CALL WITE1(DU3,DU4)
      WRITE 13
      IF(PAR .NE. NAMES(5)) GO TO 725
724   CONTINUE
      IF(IUNIT.EQ.1) WRITE 446
446   FORMAT(6X,*SOME ENGINEERING CONSTANTS, ES IN GPA*)
      IF(IUNIT.NE.1) WRITE 4461
4461  FORMAT(6X,*SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI*)
      WRITE 447,(ECON(IE),IE=1,4)
447   FORMAT(6X,*INPLANE :, E1=*,F7.3,*  E2=*,F7.3,*  V21=*,F7.3,*  E6=*
     *,F7.3)
      WRITE 448,(ECONF(IE),IE=1,4)
448   FORMAT(6X,*FLEXURAL:,EF1=*,F7.3,* EF2=*,F7.3,* VF21=*,F7.3,* EF6=*
     *,F7.3)
725   CONTINUE
      RETURN
      END




      SUBROUTINE NORM1(TPI,A,PARAM)
      INTEGER PARAM
      DIMENSION DU1(3,3),DU2(3,3),DU3(3,3),DU4(3,3),ZERO(3,3)
      DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),HLC(40),HT(40)
      DIMENSION TL(40),TT(40),DU5(3,3),DU6(3,3),DU7(3,3),DU8(3,3)
      DIMENSION DU9(3,3),DU10(3,3),PNV(3),QNV(3),DUM(3,3),A(3,3)
      DIMENSION NAMES(4),D7(3,3),DM(3,3)
      COMMON /UNIT/ IUNIT
      COMMON /BLH/ H,HI
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON/BLK/HLC,HT,TL,TT
      COMMON /BLDU/ DU2,DU4,DU5,DU7
      DATA NAMES /10HDIMENSIONL,10HNORMALIZED,4HBOTH,4H    /
13    FORMAT(5X,*-----------------------------------------------------
     *--------*)
      HSQ=H*H
      HI=1./H
      HIS=1./HSQ
      TPN1=TPI*H
      TPN2=HSQ*TPI/2.
      TPN3=TPN1*HSQ/12.
      TPNN=TPN2/3.
      DO 75 I=1,3
      DO 75 J=1,3
75    ZERO(I,J)=0.
```

```
      CALL MATM(A,SB2,DU1)
      CALL MATM(SB2,DU1,DU2)
      CALL MTAD(SB3,DU2,DU3,-1.)
      CALL INVRS(DU3,DU4)
      CALL MATM(DU1,DU4,DU5)
      CALL MATM(SB2,A,DU1)
      CALL MATM(DU5,DU1,DU6)
      CALL MATM(DU4,DU1,DU2)
      CALL MTAD(A,DU6,DU7,1.)
      CALL MTAD(ZERO,DU5,DUM,-1.)
      CALL MTAD(ZERO,DU7,D7,1.)
      CALL MTAD(ZERO,DUM,DM,1.)
      CALL MTAD(ZERO,DU7,DU1,TPN1)
      CALL MTAD(ZERO,DUM,DU8,TPNN)
      CALL MTAD(ZERO,DU2,DUM,-1.)
      CALL MTAD(ZERO,DUM,DU9,TPN2)
      CALL MTAD(ZERO,DU4,DU10,TPN3)
      IF(PARAM .EQ.NAMES(4)) GO TO 74
      IF(PARAM .EQ.NAMES(1)) GO TO 71
      IF(PARAM .EQ.NAMES(2)) GO TO 72
71    CONTINUE
      WRITE 13
      WRITE 16
      WRITE 17
16    FORMAT(35X,*ALPHA    BETA *,//)
17    FORMAT(35X,*TRSBTA   DELTA*)
      WRITE 13
      CALL WITE(D7,DM)
      CALL WITE(DUM,DU4)
      WRITE 555
555   FORMAT(6X,*NONMECH. STRESS AND MOMENT RESULTANTS N,M*)
      CALL WRT(P,5)
      CALL WRT(QQ,5)
      WRITE 13
      IF(PARAM .NE.NAMES(3)) GO TO 74
72    CONTINUE
      WRITE 44
44    FORMAT(35X,* ALPHA#    BETA#/3*,//)
      IF( IUNIT .EQ. 1) WRITE 45
      IF( IUNIT .NE. 1) WRITE 4451
45    FORMAT(35X,* TRSBTA#   DELTA#       (1./TPA)   *)
4451  FORMAT(35X,* TRSBTA#   DELTA#       1.0E-09/PSI*)
      WRITE 13
      CALL WITE1(DU1,DU8)
      CALL WITE1(DU9,DU10)
      DO 557 IST=1,3
      PNV(IST)=P(IST)*HI
      QNV(IST)=6.*QQ(IST)*HIS
557   CONTINUE
      WRITE 556
556   FORMAT(6X,*NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#*)
      CALL WRT(PNV,5)
      CALL WRT(QNV,5)
      WRITE 13
74    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PLT(X,X1,XX,X2,XXX,X3,XC,XC1,XXC,XC2,XXXC,XC3,N,TH,IC)
      INTEGER SMBL,IMM,PLANE
      DIMENSION X(200),X1(200),XX(200),X2(200),XXX(200),X3(200),XC(200),
     *XC1(200),XXC(200),XC2(200),XXXC(200),XC3(200)
      DIMENSION TH(40),NAME(2)
      COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
      COMMON /SMB/ SMBL,IMM
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      DATA NAME /9HSUPERPOSE,2HQR/
      N2=N+1
      N3=N+2
      X(N2)=PXX
      X(N3)=PXXI
      X1(N2)=PYY
      X1(N3)=PYYI
      PYS=PYY/PYYI
      PXS=PXX/PXXI
      DDY=2.55
      IF(PLANE .EQ. NAME(2)) DDY=3.55
      DDY1=DDY-.3
      DDY2=DDY-.6
      IF(SMBL .EQ. NAME(1) .AND. IMM .GT. 1) GO TO 3
      CALL SPAXIS(0.,PYS,1H ,1,YUL,90.,X1(N2),X1(N3),0.2,3.,.2,0.,2.,IT,
     *.15)
      CALL SPAXIS(PXS,0.,1H ,-1,7.0,0.,X(N2),X(N3),2.25,.1,.25,0.,2.,IT,
     *.15)
 3    CONTINUE
      IF(IC .EQ. 1) GO TO 1
      IF(IC .EQ. 2) GO TO 2
      XC(N2)=0.
      XC(N3)=PXXI
      XC1(N2)=0.
      XC1(N3)=PYYI
      XXC(N2)=0.
      XXC(N3)=PXXI
      XC2(N2)=0.
      XC2(N3)=PYYI
      XXXC(N2)=0.
      XXXC(N3)=PXXI
      XC3(N2)=0.
      XC3(N3)=PYYI
      IF(SMBL .EQ. NAME(1)) GO TO 4
      CALL NUMBER(1.0,DDY,.15,TH(1),0.,1)
      CALL FLINE(XC,XC1,-N,1,10,5)
      CALL NUMBER(1.0,DDY1,.15,TH(2),0.,1)
      CALL FLINE(XXC,XC2,-N,1,10,6)
      CALL NUMBER(1.0,DDY2,.15,TH(3),0.,1)
      CALL FLINE(XXXC,XC3,-N,1,10,7)
      GO TO 1
 4    CONTINUE
      CALL FLINE(XC,XC1,-N,1,0,5)
      CALL FLINE(XXC,XC2,-N,1,0,6)
      CALL FLINE(XXXC,XC3,-N,1,0,7)
 1    CONTINUE
```

```
      X3(N2)=0.
      X3(N3)=PYYI
      XXX(N2)=0.
      XXX(N3)=PXXI
      X2(N2)=0.
      X2(N3)=PYYI
      XX(N2)=0.
      XX(N3)=PXXI
      IF(SMBL .EQ. NAME(1)) GO TO 5
      CALL SYMBOL(.5, DDY2,.15,7,0.,-1)
      CALL FLINE(XXX,X3,-N,1,10,7)
      CALL SYMBOL(.5, DDY1,.15,6,0.,-1)
      CALL FLINE(XX,X2,-N,1,10,6)
      GO TO 2
5     CONTINUE
      CALL FLINE(XXX,X3,-N,1,0,7)
      CALL FLINE(XX,X2,-N,1,0,6)
2     CONTINUE
      X1(N2)=0.
      X(N2)=0.
      IF(SMBL .EQ. NAME(1)) GO TO 6
      CALL SYMBOL(.5, DDY ,.15,5,0.,-1)
      CALL FLINE(X,X1,-N,1,10,5)
      CALL PLOT(13.,0.,3)
      CALL PLOT(13.,0.,-2)
      RETURN
6     CONTINUE
      CALL FLINE(X,X1,-N,1,0,5)
      RETURN
      END
```

```
      SUBROUTINE PLTEN(TH,HL,HS,PMI,ZERO,PLNM)
      INTEGER PARAM2,PARAM3
      DIMENSION NAME(3),PLNM(20)
      DIMENSION SB1(3,3),SB2(3,3),SB3(3,3),P(3),QQ(3),DUM(3,3),X(200)
      DIMENSION ZERO(3,3),ECON1(200),ECON2(200),ECON3(200),ECON4(200)
      DIMENSION TH(40),HL(40),HLC(40),HT(40),TL(40),TT(40),HS(41)
      DIMENSION ES11(40),ES22(40),GS12(40),VS12(40),A(3,3)
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON /BLH/ H,HI
      COMMON /UNIT/ IUNIT
      COMMON /SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON /BLK/HLC,HT,TL,TT
      COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
      COMMON /BLM/ PARAM2,PARAM3
      DATA NAME/6HPLTEND,8HPLTSTART,6HPLTONE/
      IF(PARAM2 .EQ. NAME(3)) GO TO 7
      IF(PARAM2 .NE. NAME(2)) GO TO 6
7     CONTINUE
      CALL PLOTS(DUM,DUM,99)
      CALL PLOT(5.,2.,3)
      CALL PLOT(5.,2.,-2)
6     CONTINUE
      DO 1 II=1,91
      X(II)=TH(3)
      CALL MOLS(TH,HL,HS)
      CALL INVRS(SB1,A)
      CALL MTAD(ZERO,A,DUM,H)
      ECON1(II)=PMI/DUM(1,1)
      ECON2(II)=PMI/DUM(2,2)
      ECON4(II)=PMI/DUM(3,3)
      ECON3(II)=-DUM(1,2)/DUM(1,1)
      TH(3)=TH(3)+1.
      TH(4)=-TH(3)
      TH(5)=TH(4)
      TH(6)=TH(3)
1     CONTINUE
      YUL=6.0
      PXX=0.
      PXXI=15.0
      PYY=0.
      CONT=1.
      IF(IUNIT .EQ. 1) CONT=10.0
      PYYI=5.*CONT
      IF(IUNIT .EQ. 1) CALL SYMBOL(.1,4.5,.15,3HGPA,0.,3)
      IF(IUNIT .NE. 1) CALL SYMBOL(.1,4.5,.15,3HMSI,0.,3)
      CALL SYMBL(3.,5.,TH,PLNM,NNL,0)
      CALL SYMBOL(0.2,5.0,.2,1HE,0.,1)
      CALL SYMBOL(6.2,0.2,.2,140,0.,-1)
      CALL SYMBOL(1.00,2.55,.15,1HE,0.,1)
      CALL SYMBOL(1.15,2.45,.15,2H11,0.,2)
      CALL SYMBOL(1.00,2.25,.15,1HE,0.,1)
      CALL SYMBOL(1.15,2.15,.15,2H22,0.,2)
      CALL SYMBOL(1.00,1.95,.15,1HE,0.,1)
      CALL SYMBOL(1.15,1.85,.15,2H6 ,0.,2)
      CALL PLT(X,ECON1,X,ECON2,X,ECON4,X,ECON1,X,ECON2,X,ECON4,91,TH,1)
      PYYI=0.2
      CALL SYMBL(3.,5.,TH,PLNM,NNL,0)
      CALL SYMBOL(6.2,0.2,.2,140,0.,-1)
      CALL SYMBOL(0.2,5.0,.25,133,0.,-1)
```

```
      CALL SYMBOL(0.35,4.9,.10,2H21,0.,2)
      CALL SYMBOL(1.00,2.55,.15,133,0.,-1)
      CALL SYMBOL(1.15,2.45,.15,2H21,0.,2)
      IT=1
      CALL PLT(X,ECON3,X,ECON2,X,ECON4,X,ECON1,X,ECON2,X,ECON4,91,TH,2)
      IT=0
      IF(PARAM2.EQ.NAME(3)) GO TO 8
      IF(PARAM2 .NE. NAME(1)) GO TO 5
8     CONTINUE
      CALL PLOTE(N)
5     CONTINUE
      WRITE 3
3     FORMAT(10X,*PLOTS FOR ENGINEERING CONSTANTS DRAWN*)
      RETURN
      END
```

```
      SUBROUTINE ROOTS(A,B,C,SM,SMN)
      A2=2.0*A
      BS=B*B
      DC=BS-2.0*A2*C
      DS=SQRT(DC)
      SM=(DS-B)/A2
      SMN=-(B+DS)/A2
      RETURN
      END
```

```
      SUBROUTINE SETAN(AN,DCN)
      INTEGER PLANE,SPACE,CRITRIA
      DIMENSION AN(3),NAME(2)
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      DATA NAME/2HQR,6HSTRAIN/
      IF(PLANE .EQ. NAME(1)) GO TO 1
      AN(1)=COSM(DCN)
      AN(2)=SINM(DCN)
      AN(3)=0.
      RETURN
1     CONTINUE
      SQ2=SQRT(2.)
      AN(1)=SQ2*COSM(DCN)
      AN(2)=-AN(1)
      AN(3)=SQ2*SINM(DCN)
      IF(SPACE .EQ. NAME(2)) AN(3)=AN(3)/2.
      RETURN
      END


      SUBROUTINE STPLT(TH,HS,PM,PLNM)
      INTEGER PARAM2,PARAM3,CRITRIA,SPACE,PLANE,SMBL,MULTI
      DIMENSION VN(3),PLNM(40)
      DIMENSION GS(3,3),GSB(3)
      DIMENSION NAME(14)
      DIMENSION Q(3,3),HL(40),TH(40),SFLN(40)
      DIMENSION SPLC(40),STX1(200),STY1(200),SCX1(200),SCY1(200)
      DIMENSION STX2(200),STY2(200),SCX2(200),SCY2(200)
      DIMENSION STX3(200),STY3(200),SCX3(200),SCY3(200)
      DIMENSION GB(3),G(3,3),SFLL(40),SFU(40),EN1(3),END(3),QQ(3)
      DIMENSION SB3(3,3),HT(40),TL(40),TT(40),P(3),HLC(40)
      DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
      DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
      DIMENSION DU2(3,3),DU4(3,3),DU5(3,3),E1(3),E2(3),E3(3),E4(3)
      DIMENSION ETR(3),ENT(3),U(5),DU7(3,3),HS(21),AN(3),AM(3)
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON/BLK/HLC,HT,TL,TT
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON /UNIT/ IUNIT
      COMMON /BLH/ H,HI
      COMMON /BLDU/ DU2,DU4,DU5,DU7
      COMMON /BKK9/ PXX,PXXI,PYY,PYYI,YUL,IT
      COMMON /SMB/ SMBL,IMM
      COMMON /BLM/ PARAM2,PARAM3
      COMMON /SF/SFL,COUNT
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      COMMON /ST1/ STX1,STY1,SCX1,SCY1,NSF1
      COMMON /ST2/ STX2,STY2,SCX2,SCY2,NSF2
      COMMON /ST3/ STX3,STY3,SCX3,SCY3,NSF3
```

```
      DATA NAME/6HPLTEND,8HPLTSTART,7HTSAI WU,9HMAXSTRESS,
     *9HMAXSTRAIN,6HSTRAIN,6HSTRESS,6HCHAMIS,7HHOFFMAN,4HHILL,6HPLTONE,
     *2HQR,9HSUPERPOSE,9HMULTICURV/
      COUNT=1.
      FCTRS=1.
      FCTRF=1.
      READ 705,CRITRIA,SPACE,PLANE,SMBL,FS12,MULTI,FCTRS,FCTRF
705   FORMAT(4A10,F10.3,A10,2F10.3)
      IF(PARAM3 .EQ. NAME(11)) GO TO 716
      IF(PARAM3 .NE. NAME(2)) GO TO 701
716   CONTINUE
      CALL PLOTS(DUM,DUM,99)
      CALL PLOT(5.,5.,3)
      CALL PLOT(5.,5.,-2)
      IF(FCTRF .EQ. 0.) FCTRF=1.
      CALL FACTOR(FCTRF)
701   CONTINUE
      YUL=8.
      IT=0
      IF(FCTRS .EQ. 0.) FCTRS=1.
      CONT=FCTRS*1.
      IF(IUNIT .EQ. 1) CONT=FCTRS*10.0
      PXX=-400.0*CONT
      PXXI=100.0*CONT
      PYY=-500.0*CONT
      PYYI=PXXI
      IF(PLANE .NE. NAME(12)) GO TO 726
      PXX=-75.0*CONT
C     PXX=-150.0*CONT
C     PXXI=50.0*CONT
      PXXI=25.0*CONT
C     PYY=-200.0*CONT
      PYY=-100.0*CONT
      PYYI=PXXI
726   CONTINUE
      NPT=91
      MM=NNL/2
      IF(SMBL .NE. NAME(13)) MM=1
      DO 722 IMM=1,MM,3
725   CONTINUE
      DO 601 ICND=1,NPT
      DCN=180*(ICND-1)/(NPT-1)
      CALL SETAN(AN,DCN)
      AM(1)=0.
      AM(2)=0.
      AM(3)=0.
      NSF1=1
      NSF2=2
      NSF3=3
      DO 600 IK=NSF1,NSF3
      K=IMM+IK-1
      IF(K .GT. NNL) K=1
      IF(ES11(K) .EQ. 0.0) GO TO 600
      DO 109 I=1,3
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 209 J=1,3
      SUM1=SUM1+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K)*(-DU2(I,J)*AN(J)+
```

```
     *DU4(I,J)*AM(J))
      SUM2=SUM2+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K+1)*(-DU2(I,J)*AN(J)+
     *DU4(I,J)*AM(J))
      SUM3=SUM3+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K)*(-DU2(I,J)* P(J)+
     *DU4(I,J)*QQ(J))
      SUM4=SUM4+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K+1)*(-DU2(I,J)* P(J)+
     *DU4(I,J)*QQ(J))
209   CONTINUE
      E1(I)=SUM1
      E2(I)=SUM2
      E3(I)=SUM3
      E4(I)=SUM4
109   CONTINUE
C    E1(J)  =MECHANICAL STRAIN COMPONENTS LOWER SURFACE
C    E2(J)  =MECHANICAL STRAIN COMPONENTS UPPER SURFACE
C    E4(J)  =NONMECHANICAL STRAIN COMPONENTS UPPER SURFACE
C    E3(J)  =NONMECHANICAL STRAIN COMPONENTS LOWER SURFACE
      THT=TH(K)
      CALL TRE(E1,ETR,THT)
      CALL TRE(E3,ENT,THT)
      CALL NMSN(C,DT,EN1,HLC,HT,TL,TT,K)
      CALL VDI(ENT,EN1,END)
      CALL MODULS(ES11(K),ES22(K),VS12(K),GS12(K),Q,U)
      IF(CRITRIA .EQ. NAME(4) .AND. SPACE .EQ. NAME(7)) GO TO 702
      IF(CRITRIA .EQ. NAME(5) .AND. SPACE .EQ. NAME(7)) GO TO 703
      IF(SPACE .EQ. NAME(6)) GO TO 708
      IF(SPACE .EQ. NAME(7)) GO TO 709
708   CALL TRE(AN,ETR,THT)
      IF(FCTRS EQ. 0.0) FCTRS=1.
      PXX=-.04*FCTRS
      PXXI=.01*FCTRS
      PYY=-.05*FCTRS
      PYYI=PXXI
      IT=2
      IF(CRITRIA .EQ. NAME(4)) GO TO 702
      IF(CRITRIA .EQ. NAME(5)) GO TO 703
      CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
      CALL COEF(G,GB,GS,GSB,THT)
      CALL FSFTY(AN,END,GS,GSB,SM,SMN)
      SFLN(IK)=SM
      CALL VNF(AN,VN)
      CALL TRE(VN,ETR,THT)
      CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
      CALL COEF(G,GB,GS,GSB,THT)
      CALL FSFTY(AN,END,GS,GSB,SM,SMN)
      SPLC(IK)=SMN
      GO TO 600
709   CONTINUE
      CALL FAILCO(ETR,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
      CALL FSFTY(ETR,END,G,GB,SM,SMN)
      SFLN(IK)=SM/(H*PM)
      IF(CRITRIA .NE. NAME(8)) GO TO 710
      CALL VNF(ETR,VN)
      CALL FAILCO(VN,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
      CALL FSFTY(ETR,END,G,GB,SM,SMN)
710   CONTINUE
      SFLL(IK)=SM
      SPLC(IK)=SMN/(H*PM)
      GO TO 600
702   CONTINUE
```

```
      CALL MVM(Q,ETR,E1)
      CALL MXSTRS(K,E1,AN,PM)
      IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
      SFLN(IK)=SFL
      CALL VNF(E1,VN)
      CALL MXSTRS(K,VN,AN,PM)
      IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
      SPLC(IK)=-SFL
      GO TO 600
703   CONTINUE
      CALL MXSTRN(K,ETR,AN,Q,PM)
      IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
      SFLN(IK)=SFL
      CALL VNF(ETR,VN)
      CALL MXSTRN(K,VN,AN,Q,PM)
      IF(SPACE .EQ. NAME(6)) SFL=SFL*H*PM
      SPLC(IK)=-SFL
600   CONTINUE
      CALL ADJUST(ICND,SFLN,SPLC,AN)
601   CONTINUE
      IF(IMM .GT. 1) GO TO 721
      IF(PLANE .EQ. NAME(12)) GO TO 718
      IF(SMBL .NE. NAME(13)) CALL SYMBL(-3.0,2.75,TH,PLNM,NNL,1)
C     CALL RECT(-4.,-5.,8.0,6.0,0.,3)
      IF(SPACE .EQ. NAME(7)) GO TO 711
      CALL SYMBOL(-.3,2.4,.25,129,0.,-1)
      CALL SYMBOL(1.6,.35,.25,129,0.,-1)
      GO TO 712
711   CONTINUE
      CALL SYMBOL(-.3,2.4,.25,108,0.,-1)
      CALL SYMBOL(1.6,.35,.25,108,0.,-1)
      IF(IUNIT .EQ. 1) CALL SYMBOL(-.5,2.,.15,3HMPA,0.,3)
      IF(IUNIT .NE. 1) CALL SYMBOL(-.5,2.,.15,3HKSI,0.,3)
712   CONTINUE
      CALL SYMBOL(-.1,2.30,.10,1H2,0.,1)
      CALL SYMBOL(-.1,2.55,.10,1H0,0.,1)
      CALL SYMBOL(1.8,0.25,.10,1H1,0.,1)
      CALL SYMBOL(1.8,0.50,.10,1H0,0.,1)
      GO TO 719
718   CONTINUE
      IF(SMBL .NE. NAME(13)) CALL SYMBL(-2.3,3.75,TH,PLNM,NNL,1)
C     CALL RECT(-3.,-4.,8.0,6.0,0.,3)
      CALL SYMBOL(-.5,3.4,.2,2H2R,0.,2)
      CALL SYMBOL(-.7,3.4,.2,25,0.,-1)
      CALL SYMBOL(2.4,.35,.2,2H2Q,0.,2)
      CALL SYMBOL(2.2,.35,.2,25,0.,-1)
      IF(SPACE .EQ. NAME(7)) GO TO 720
      CALL SYMBOL(2.8,0.25,.15,129,0.,-1)
      CALL SYMBOL(-.1,3.3,.15,129,0.,-1)
      GO TO 719
720   CONTINUE
      CALL SYMBOL(2.8,0.25,.15,108,0.,-1)
      CALL SYMBOL(-.1,3.3,.15,108,0.,-1)
      IF(IUNIT .EQ. 1) CALL SYMBOL(-.5,3.,.15,3HMPA,0.,3)
      IF(IUNIT .NE. 1) CALL SYMBOL(-.5,3.,.15,3HKSI,0.,3)
719   CONTINUE
      DDX=-2.85
      DDY=-3.7
      IF(CRITRIA .EQ. NAME(3) .OR. CRITRIA .EQ. NAME(8)) GO TO 900
      GO TO 901
```

```
900   CALL SYMBOL(0.8,-3.5,0.15,4HF  =,0.,4)
      CALL NUMBER(1.5,-3.5,0.15,FS12,0.,1)
      CALL SYMBOL(0.95,-3.6,0.12,2HXY,0.,2)
      CALL SYMBOL(1.05,-3.3,0.12,11,0.,-1)
901   CONTINUE
      IF(CRITRIA .EQ. NAME(3)) CALL SYMBOL(DDX,DDY,0.15,16HTSAI WU CRITE
     *RIA,0.,16)
      IF(CRITRIA .EQ. NAME(4)) CALL SYMBOL(DDX,DDY,.15,10HMAX STRESS,0.,
     *10)
      IF(CRITRIA .EQ. NAME(5)) CALL SYMBOL(DDX,DDY,.15,10HMAX STRAIN,0.,
     *10)
      IF(CRITRIA .EQ. NAME(8)) CALL SYMBOL(DDX,DDY,0.15,15HCHAMIS CRITER
     *IA,0.,15)
      IF(CRITRIA .EQ. NAME(9)) CALL SYMBOL(DDX,DDY,0.15,16HHOFFMAN CRITE
     *RIA,0.,16)
      IF(CRITRIA .EQ. NAME(10)) CALL SYMBOL(DDX,DDY,0.15,16HHILL CRITERI
     *A   ,0.,16)
721   CONTINUE
      CALL PLT(STX1,STY1,STX2,STY2,STX3,STY3,SCX1,SCY1,SCX2,SCY2,SCX3,
     *SCY3,NPT,TH,9)
722   CONTINUE
      IF(MULTI .EQ. NAME(14)) GO TO 729
      IF(SMBL .EQ. NAME(13)) GO TO 728
      GO TO 729
728   CALL PLOT(13.,0.,3)
      CALL PLOT(13.,0.,-2)
729   CONTINUE
      IF(PARAM3 .EQ. NAME(11)) GO TO 717
      IF(PARAM3.NE.NAME(1)) GO TO 6
717   CONTINUE
      CALL PLOTE(N)
6     CONTINUE
      WRITE 11
11    FORMAT(5X,*FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED*)
      RETURN
      END


      SUBROUTINE STRNG(TH,HS,PM,NLDCN)
      INTEGER CRITRIA,SPACE,PLANE
      DIMENSION Q(3,3),HL(40),TH(40),SFLN(40),SFUN(40)
      DIMENSION GB(3),G(3,3),SFLL(40),SFU(40),EN1(3),END(3),QQ(3)
      DIMENSION SB3(3,3),HT(40),TL(40),TT(40),P(3),HLC(40)
      DIMENSION SXC(40),SXL(40),SYL(40),SYC(40),SXLT(40)
      DIMENSION ES11(40),ES22(40),VS12(40),GS12(40),SB1(3,3),SB2(3,3)
      DIMENSION DU2(3,3),DU4(3,3),DU5(3,3),E1(3),E2(3),E3(3),E4(3)
      DIMENSION ETR(3),ENT(3),U(5),DU7(3,3),HS(41),AN(3),AM(3)
      DIMENSION NAMES(3),ETR2(3)
      COMMON /BLK2/ ES11,ES22,VS12,GS12,NNL
      COMMON/BLK/HLC,HT,TL,TT
      COMMON/SBS/SB1,SB2,SB3,P,QQ,DT,C
```

```
      COMMON /BLK1/ SXL,SXC,SYL,SYC,SXLT,HL
      COMMON /UNIT/ IUNIT
      COMMON /BLH/ H,HI
      COMMON /BLDU/ DU2,DU4,DU5,DU7
      COMMON /SF/SFL,COUNT
      COMMON /CRIT/ CRITRIA,SPACE,PLANE,FS12
      NAMELIST /STRESS/ AN,AM
      DATA NAMES/7HTSAI WU,9HMAXSTRAIN,9HMAXSTRESS/
      COUNT=2.
      READ 700,CRITRIA,SPACE,PLANE,SMBL,FS12
      IF(NLDCN .EQ. 1) READ STRESS
700   FORMAT(4A10,F10.3)
      DO 601 ICND=1,NLDCN
      IF(NLDCN.EQ.1) GO TO 602
      READ STRESS
602   CONTINUE
      WRITE 13
      WRITE 603
603   FORMAT(6X,*APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M*)
      CALL WRT1(AN)
      CALL WRT1(AM)
      WRITE 13
      DO 600 K=1,NNL
      IF(ES11(K) .EQ. 0.0) GO TO 600
      DO 109 I=1,3
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 209 J=1,3
      SUM1=SUM1+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K)*(-DU2(I,J)*AN(J)+
     *DU4(I,J)*AM(J))
      SUM2=SUM2+DU7(I,J)*AN(J)-DU5(I,J)*AM(J)+HS(K+1)*(-DU2(I,J)*AN(J)+
     *DU4(I,J)*AM(J))
      SUM3=SUM3+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K)*(-DU2(I,J)* P(J)+
     *DU4(I,J)*QQ(J))
      SUM4=SUM4+DU7(I,J)* P(J)-DU5(I,J)*QQ(J)+HS(K+1)*(-DU2(I,J)* P(J)+
     *DU4(I,J)*QQ(J))
209   CONTINUE
      E1(I)=SUM1
      E2(I)=SUM2
      E3(I)=SUM3
      E4(I)=SUM4
109   CONTINUE
C    E1(J)  =MECHANICAL STRAIN COMPONENTS LOWER SURFACE
C    E2(J)  =MECHANICAL STRAIN COMPONENTS UPPER SURFACE
C    E4(J)  =NONMECHANICAL STRAIN COMPONENTS UPPER SURFACE
C    E3(J)  =NONMECHANICAL STRAIN COMPONENTS LOWER SURFACE
      WRITE 4494
4494  FORMAT(5X,*EFFECTIVE NONMECHANICAL STRAIN COMP. AT LOWER SURF.*)
      CALL WRT(E3,5)
      WRITE 13
      WRITE 18,TH(K)
13    FORMAT(5X,*-------------------------------------------------------
     *--------*)
18    FORMAT(5X,*ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =*,F5.1)
      WRITE 19
19    FORMAT(5X,*MECH/NONMECH    LOWER SURF.     UPPER SURF. *)
      WRITE 20
20    FORMAT(5X,*  MECH.              1                 2    *)
```

```
      WRITE 21
21    FORMAT(5X,*  NONMECH.          3                  4 *)
      WRITE 13
      THT=TH(K)
      CALL TRE(E1,ETR,THT)
      CALL TRE(E3,ENT,THT)
      CALL NMSN(C,DT,EN1,HLC,HT,TL,TT,K)
      CALL VDI(ENT,EN1,END)
      CALL MODULS(ES11(K),ES22(K),VS12(K),GS12(K),Q,U)
      CALL FAILCO(E1,Q,SXL(K),SXC(K),SYL(K),SYC(K),SXLT(K),G,GB)
      CALL FSFTY(ETR,END,G,GB,SM,SMN)
      WRITE 701
      WRITE 13
      CALL WRT(ETR,1)
      CALL MVM(Q,ETR,E1)
      SFLL(K)=SM
      SFLN(K)=SM/(H*PM)
      CALL TRE(E2,ETR2,THT)
      CALL WRT(ETR2,2)
      CALL MVM(Q,ETR2,E2)
      CALL WRT(END,3)
      CALL MVM(Q,END,E3)
      CALL TRE(E4,ENT,THT)
      CALL VDI(ENT,EN1,END)
      CALL WRT(END,4)
      CALL MVM(Q,END,E4)
701   FORMAT (10X,*STRAIN COMPONENTS*)
      WRITE 13
703   FORMAT (10X,*STRESS COMPONENTS*)
      WRITE 703
      WRITE 13
      CALL WRT(E1,1)
      CALL WRT(E2,2)
      CALL WRT(E3,3)
      CALL WRT(E4,4)
      CALL FSFTY(ETR2,END,G,GB,SM,SMN)
      SFU(K)=SM
      SFUN(K)=SM/(H*PM)
      WRITE 13
      IF(CRITRIA .EQ. NAMES(2)) GO TO 502
      IF(CRITRIA .EQ. NAMES(3)) GO TO 503
501   WRITE 510,CRITRIA
510   FORMAT(5X,A10,*FAILURE CRITERIA*)
      WRITE 606,SFLL(K),SFU(K)
606   FORMAT(5X,*STRENGTH RATIO R: LOWER SURF.=*,E10.3,*  UPPER SURF.=*,
     *E10.3)
      IF(IUNIT .EQ.1) GO TO 4492
      WRITE 4491,SFLN(K),SFUN(K)
      GO TO 4493
4492  WRITE 449,SFLN(K),SFUN(K)
4493  CONTINUE
449   FORMAT(5X,*STRENGTH R# MPA : LOWER SURF.=*,F10.3,*  UPPER SURF.=*,
     *F10.3)
4491  FORMAT(5X,*STRENGTH R# KSI : LOWER SURF.=*,F10.3,*  UPPER SURF.=*,
     *F10.3)
      WRITE 13
      GO TO 504
502   WRITE 505
505   FORMAT(5X,*MAXIMUM STRAIN FAILURE CRITERIA*)
      WRITE 506
```

```
506   FORMAT(5X,*MAX APPLIED STRESS RESULTANTS/ AVERAGE STRESSES*)
      WRITE 13
      WRITE 507
507   FORMAT(5X,*LOWER SURFACE*)
      CALL MXSTRN(K,ETR,AN,Q,PM)
      WRITE 508
508   FORMAT(5X,*UPPER SURFACE*)
      CALL MXSTRN(K,ETR2,AN,Q,PM)
      GO TO 504
503   WRITE 509
509   FORMAT(5X,*MAXIMUM STRESS FAILURE CRITERIA*)
      WRITE 506
      WRITE 507
      CALL MXSTRS(K,E1,AN,PM)
      WRITE 508
      CALL MXSTRS(K,E2,AN,PM)
504   CONTINUE
      WRITE 702
702   FORMAT(1H0//)
600   CONTINUE
601   CONTINUE
      RETURN
      END


      SUBROUTINE SYM(X)
      DIMENSION X(3,3)
      X(3,1)=X(1,3)
      X(3,2)=X(2,3)
      X(2,1)=X(1,2)
      RETURN
      END


      SUBROUTINE SYMBL(X,Y,TH,PLNM,N,I)
      DIMENSION TH(20),PLNM(20)
      CALL SYMBOL(X,Y,.15,4HNNL=,0.,4)
      X1=X+.6
      HNL=N
      CALL NUMBER(X1,Y,.15,HNL,0.,-1)
      X2=X-.25
      Y1=Y-.25
      CALL SYMBOL(X2,Y1,.15,144,0.,-1)
      CALL SYMBOL(X1,Y1,.15,5HPLIES,0.,5)
      XS1=X-.25
      XS2=X+.8
      YS1=Y-.55
      NHL=N/2
      DO 1 INL=1,NHL
      IF(I .EQ. 0 .AND. INL. GT. 2) GO TO 2
      IF(TH(INL) .GE. 0.) CALL NUMBER(XS1,YS1,.15,TH(INL),0.,1)
      XS3=XS1-.15
      IF(TH(INL) .LT. 0.) CALL NUMBER(XS3,YS1,.15,TH(INL),0.,1)
2     CONTINUE
```

```
      IF(I .EQ. 0 .AND. INL. GT. 2) CALL SYMBOL(XS1,YS1,.15,140,0.,-1)
      IF(I .EQ. 0 .AND. INL .EQ. 4) CALL SYMBOL(XS3,YS1,.15,1H-,0.,1)
      CALL NUMBER(XS2,YS1,.15,PLNM(INL),0.,-1)
      YS1=YS1-.3
1     CONTINUE
      RETURN
      END


      SUBROUTINE TRE(Z,T,THE)
      DIMENSION Z(3),T(3)
      TH2=2.*THE
      C=COSM(TH2)
      S=SINM(TH2)
      P=0.5*(Z(1)+Z(2))
      Q=0.5*(Z(1)-Z(2))
      R=0.5*Z(3)
      T(1)=P+Q*C+R*S
      T(2)=P-Q*C-R*S
      T(3)=-2.*(Q*S-R*C)
      RETURN
      END


      SUBROUTINE TRS(Z,T,THE)
      DIMENSION Z(3),T(3)
      TH2=2.*THE
      C=COSM(TH2)
      S=SINM(TH2)
      P=0.5*(Z(1)+Z(2))
      Q=0.5*(Z(1)-Z(2))
      R=Z(3)
      T(1)=P+Q*C+R*S
      T(2)=P-Q*C-R*S
      T(3)=-Q*S+R*C
      RETURN
      END


      SUBROUTINE US(Q,U)
      DIMENSION Q(3,3),U(5)
      SQ12=Q(1,1)+Q(2,2)
      SQ24=2.*Q(1,2)+4.*Q(3,3)
      U(1)=(3.*SQ12+SQ24)/8.
      U(2)=(Q(1,1)-Q(2,2))/2.
      U(3)=(SQ12-SQ24)/8.
      U(4)=(SQ12+6.*Q(1,2)-4.*Q(3,3))/8.
      U(5)=(SQ12-2.*Q(1,2)+4.*Q(3,3))/8.
      RETURN
      END
```

```
      SUBROUTINE VDI(A,B,C)
      DIMENSION A(3),B(3),C(3)
      DO 1 I=1,3
      C(I)=A(I)-B(I)
1     CONTINUE
      RETURN
      END

      SUBROUTINE VNF(V,VN)
      DIMENSION V(3),VN(3)
      DO 1 I=1,3
      VN(I)=-V(I)
1     CONTINUE
      RETURN
      END

      SUBROUTINE WITE(Q,A)
      DIMENSION Q(3,3),A(3,3)
      DO 1 I=1,3
      WRITE 2,(Q(I,J),J=1,3),(A(I,J),J=1,3)
2     FORMAT(2X,3E11.3,1X,3E11.3)
1     CONTINUE
      RETURN
      END

      SUBROUTINE WITE1(X,Y)
      DIMENSION X(3,3),Y(3,3)
      DO 1 I=1,3
      WRITE2,(X(I,J),J=1,3),(Y(I,K),K=1,3)
1     CONTINUE
2     FORMAT(2X,6F10.1)
      RETURN
      END

      SUBROUTINE WRITE(Q)
      DIMENSION Q(3,3)
      DO 1 I=1,3
      WRITE2,(Q(I,J),J=1,3)
2     FORMAT(10X,3(10X,E16.3))
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE WRT(X,INDX)
      DIMENSION X(3)
      IF(INDX.GT.4) GO TO 1
      WRITE2,INDX,(X(I),I=1,3)
2     FORMAT(10X,I4,3E16.3)
      RETURN
1     WRITE3,(X(I),I=1,3)
3     FORMAT(10X,3E16.3)
      RETURN
      END



      SUBROUTINE WRT1(X)
      DIMENSION X(3)
      WRITE2,(X(I),I=1,3)
2     FORMAT(10X,3F16.3)
      RETURN
      END



      FUNCTION COSM(ALPHA)
      DATA  CONV/.017453292519943/
      IF(ALPHA .EQ. 90.0 .OR. ALPHA .EQ. 270.) GO TO 10
      IF(ALPHA .EQ.-90.0 .OR. ALPHA .EQ.-270.) GO TO 10
      COSM=COS(CONV*ALPHA)
      RETURN
10    COSM=0.
      RETURN
      END

      FUNCTION SINM(ALPHA)
      DATA  CONV/.017453292519943/
      IF(ALPHA .EQ. 180. .OR. ALPHA .EQ. 360.) GO TO 10
      IF(ALPHA .EQ.-180. .OR. ALPHA .EQ.-360.) GO TO 10
      SINM=SIN(CONV*ALPHA)
      RETURN
10    SINM=0.
      RETURN
      END

      FUNCTION VVM(X,Y)
      DIMENSION X(3),Y(3)
      SUM=0.0
      DO 1 I=1,3
      SUM=SUM+X(I)*Y(I)
1     CONTINUE
      VVM=SUM
      RETURN
      END
```

USER'S INSTRUCTIONS

TRANSFORMATIONS

Objective	Card #	Input Data	Format
Stress Trans.	1	TRANSFORMb STRESS	(2A10)
	2	σ_1, σ_2, σ_6, $\theta°$	(4F10.3)
Strain Trans.	1	TRANSFORMb STRAIN	(2A10)
	2	ε_1, ε_2, ε_6, $\theta°$	(4F10.3)
Modulus Trans.	1	TRANSFORMb MODULUS	(2A10)
	2	Material+ Units*	(2A10)
	3	$\theta°$	(5F10.3)
Compliance Trans.	1	TRANSFORMb COMPLIANCE	(2A10)
	2	Material+ Units*	(2A10)
	3	$\theta°$	(5F10.3)
Modulus & Compliance Trans.	1	TRANSFORMb MODCOM	(2A10)
	2	Material+ Units*	(2A10)
	3	$\theta°$	(5F10.3)

*Units - either SI or English

+If the name of the material being used is not given in Table 1, give NEW and replace the card #3 by E_x, E_y, ν_x, E_s, $\theta°$. E_x, E_y and E_s are in GPa.

b denotes a blank column between two commands.

Input commands are punched strictly according to the format. The first letter starting from the first column of the assigned columns.

Material Properties

The material properties of seven commonly used materials, given in Table 1, are included in the program. These properties can be used by providing the corresponding material name for pure laminates and the material property identification number for hybrid laminates. If the problem under investigation requires material properties different from those given in Table 1, the existing values can be replaced through appropriate input data. The following data cards are used:

(1) NEWMTRLS   Format (A10)

(2) b$LAMDATAb NNM= , EX= , EY= ... etc. such that

NNM	=	Number of materials being read in	
EX	=	E_x for each material	
EY	=	E_y	-do-
VX	=	ν_x	-do-
ES	=	E_s	-do-
ALFX	=	α_x	-do-
ALFY	=	α_y	-do-
BTAX	=	β_x	-do-
BTAY	=	β_y	-do-
X	=	X	-do-
XD	=	X'	-do-
Y	=	Y	-do-
YD	=	Y'	-do-
S	=	S	-do-
SH	=	h_o	-do-

For the use of these properties in the mechanics problems, the corresponding names or material property identification numbers given in Table 1 are used. The units of these input quantities are the same as those of Table 1, i.e. SI units. The output results can be obtained either in SI units or in English units, by providing suitable instructions.

Laminate Analysis

On the basis of lamination theory, the effective material properties and strength characteristics of multidirectional laminates are studied by using the following input data:

(1) LAMINATE bb TYPE Format (4A10)

(2) CASE PARAM PARAM1 PARAM2 PARAM3
Format (5A10)

The various choices for the parameters - TYPE, CASE, PARAM, PARAM1-3 are given below:

TYPE	INPLANE GENERAL

CASE	PURE HYBRID

PARAM (Effective Modulus)	DIMENSIONL NORMALIZED BOTH ENGCONST ALL Blank for none

PARAM1 (Effective Compliance)	DIMENSIONL NORMALIZED BOTH Blank for none

PARAM2 (Strength)	STRENGTH STRNGTHPLT PLTSTART PLTEND PLTONE Blank for none

PARAM3 (Engg. Constants)	ENGCPLT PLTSTART PLTEND PLTONE Blank for none

(3) Title of the problem

Format (8A10)

(4) If the CASE is pure then:

(a) MATERIAL* UNITS+ (2A10)

*name of the material from Table 1

+SI or English

(b) b$LAYERbNNL= , TH= , PLNM= ,
DT= , C= , NLDCN= $

NNL = Total number of layers

TH = $\theta_1, \theta_2, \ldots \theta_{NNL}$, bottom ply is the first ply

PLNM = Number of plies corresponding to each ply orientation

DT = Temperature difference, ΔT

C = Moisture content

NLDLN = Number of loading conditions considered

In all cases when PARAM2 is not STRENGTH, NLDCN is not active and is given equal to 1. When PARAM2 is STRENGTH, NLDCN is active and will require like number of STRESS input cards following card #(5).

If the case is HYBRID then:

(c) b*$LAYERSbNNL= , LMPI= , TH= , PLNM= , IUNIT= ,
DT= , C= , NLDCN= bb$

NNL	=	Total number of layers
LMPI	=	Layer material property identification number (Table 1)
TH	=	$\theta_1, \theta_2, \theta_3 \ldots \theta_{NNL}$ starting from bottom
IUNIT	=	1 for SI and 2 for ENGLISH units
PLNM	=	Number of plies corresponding to each orientation
DT	=	Temperature difference
C	=	Moisture content
NLDCN	=	Number of loading conditions considered

(5) CRITERIA SPACE PLANE SMBL FS12 MULTICURV FCTRS FCTRF +

(IF APPLICABLE) (4A10, F10.3, A10, 2F10.3)

CRITERIA	TSAI WU CHAMIS HOFFMAN HILL MAXSTRAIN MAXSTRESS

SPACE	STRESS STRAIN

PLANE	QR PRINCIPAL

*b denotes a blank column.

+FCTRF remains the same for all cases in a computer run.

SMBL	SUPERPOSE YES

FS12: Quadratic polynomial failure criteria interaction term.

MULTICURV: If the failure surfaces following the failure surfaces being generated are going to be drawn in the same figure, use this command. Otherwise, leave blank.

FCTRS: Factor by which the scale for strength plot to be altered.

FCTRF: Factor by which the figure size in the strength plot to be altered.

(6) b$STRESSb AN = N_1, N_2, N_6, AM = M_1, M_2, M_6bb$

where AN(I), I = 1, 2, 3 = Mechanical stress resultants
AM(I), I = 1, 2, 3 = Mechanical moment resultants

(7) THEEND Format(A10)

This card denotes the end of input instructions.

Description of Each Command

TYPE: What type of laminate is being considered, INPLANE or GENERAL? If only inplane analysis is conducted, one can still use general option, but some of the outputs may not be of interest. Also because in the inplane case stacking sequence does not matter, the input instructions become a bit simpler.

CASE: Which case of the laminate material system is under consideration, PURE or HYBRID? For a pure laminate the data card stating the name of the material is sufficient, whereas in hybrid laminates the layer material property identification number (LMPI) for each ply orientation is required. This parameter (LMPI) is given in $LAYERS card. The description of LAYERS card is given in #(4)c, page 69.

PARAM: What quantities in the effective modulus of the laminate are required?

DIMENSIONL: Dimensional effective modulus matrices A, B, and D.

NORMALIZED: Normalized effective modulus matrices A*, B*, and D*.

BOTH: Both dimensional and normalized modulus matrices A, B, D and A*, B*, D*.

ENGCONST: Effective inplane engineering constants of the laminate E_1°, E_2°, ν_{21}°, E_6° and effective flexural engineering constants E_1^f, E_2^f, ν_{21}^f, E_6^f.

ALL: All the aforementioned quantities.

Blank: If you don't want any of these quantities leave this column blank.

PARAM1: What quantities in the effective compliance of the composite laminate are required?

DIMENSIONL: Dimensional effective compliance matrices α, β, δ.

NORMALIZED: Normalized effective compliance matrices α^*, β^*, δ^*.

BOTH: Both dimensional and normalized compliance matrices α, β, δ and α^*, β^*, δ^*.

PARAM2: This command controls the strength predictions and plotting the failure surface.

STRENGTH: Computes the strength ratio R for each ply orientation and corresponding parameter R/h

for a given loading condition. These parameters are calculated on the basis of six different failure criteria viz. Tsai Wu, Chamis, Hoffman, Hill, maximum stress (MAXSTRESS) and maximum strain (MAXSTRAIN) failure criteria. The criteria to be used has to be assigned at an appropriate place in the input data.

STRNGTHPLT: This command generates failure surfaces for each ply orientation of the laminate. The program is set such that it will give failure surfaces for the first three ply orientations, or all the ply orientations. For obtaining failure envelopes for all the plies in the laminate if the number of plies is more than 6, the SMBL parameter in card number 5 is SUPERIMPOSE, otherwise blank. There is a choice of failure criteria space, plane and the failure criteria interaction term F^*_{xy}, as given in card 5.

PLTSTART: If the plot assigned by this card is the first strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTSTART.

PLTEND: If the plot assigned by this card is the last strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTEND.

PLTONE: If there is only one strength (engineering constant) plot in the Job PARAM3 (PARAM2) should be PLTONE.

Blank: If no strength/effective engineering constants plot is required leave these columns blank.

PARAM3: This command controls the plots of effective engineering constants versus the angle ply ϕ in the laminate $(\theta_n/\overline{\theta}_p/\pm\phi_q)_s$.

ENGCPLT: This command will give the plot of the effective engineering constants E_1°, E_2°, E_6° and ν_{21}°.

PLTSTART, PLTEND, PLTONE: As mentioned in PARAM2.

Blank: If no effective engineering constants/strength plot is required.

CRITERIA: There is a choice of failure theories that can be used for finding the successive ply strengths of the laminate. Six failure theories [9] have been included in the program. In the quadratic polynomial failure criteria, the hygrothermal effects are included whereas in the Max. stress and the Max. strain failure theories these effects are not included.

SPACE: The failure surfaces can be obtained either in stress space or in strain space.

PLANE: Stress space and strain spaces can be represented either in principal stress or strain loadings or in qr plane loading in which:

$$p_\varepsilon = (\varepsilon_1 + \varepsilon_2)/2 = 0$$

$$q_\varepsilon = (\varepsilon_1 - \varepsilon_2)/2\ , \quad r_\varepsilon = \varepsilon_6/2$$

$$p_\sigma = (\sigma_1 + \sigma_2)/2 = 0$$

$$q_\sigma = (\sigma_1 - \sigma_2)/2$$

$$r_\sigma = \sigma_6$$

By assigning the PLANE parameter as QR a strength plot in qr space can be obtained. Otherwise the strength plot will be in principal strain or stress space as the case may be.

SMBL: This input parameter controls the plotting of failure surfaces w.r.t. the number of plies for which the failure surfaces are plotted. SUPERPOSE will plot the failure envelopes of all the plies if the number of plies is up to 50. If the corresponding columns are left blank, failure envelopes for the first three layers will be plotted. The laminate layer data should be given such that the first three orientations are of prime interest.†

FS12: The failure criteria interaction term (F^*_{xy}) in the case of Tsai Wu and Chamis failure criteria.

MULTICURV: In case the failure envelopes generated by the current data input is going to be plotted on the same figure as those generated by the following data set provide the command MULTICURV in the corresponding columns, otherwise leave these columns blank.

FCTRS: For changing the scale of the strength plot, i.e. for reducing the scale to 1/2, FCTRS is given as 0.5.

FCTRF: For changing the figure size in the strength plot, i.e. for increasing the figure size by 25%, FCTRF is given as 1.25. FCTRF < 1.4.

†For laminates with a number of ply orientations less than 3, laminate data should be arranged such that NNL≥3. This precaution is taken to avoid the use of unspecified values of θ_i, (i=2,3) in case NNL=1, stored in the available spaces.

ILLUSTRATIONS

I. Transformation of in-plane stress (σ_1, σ_2, σ_6) through an angle θ.

σ_1 = 10, MPa, σ_2 = 15. MPa, σ_6 = 12. MPa, θ = 27.5°

Input data:

```
TRANSFORM STRESS
  10.          15.         12.         27.5
THEEND
```

Output:

```
STRESS TRANSFORMATION THRU    27.5  DEGREES
                         SIGMA1     SIGMA2     SIGMA6
-----------------------------------------------------
GIVEN                    10.000     15.000     12.000
TRANSFORMED              20.896      4.104      8.931
-----------------------------------------------------
```

II. Transformation of in-plane strain (ε_1, ε_2, ε_6) through an angle θ.

ε_1 = 2.0, ε_2 = .05, ε_6 = 1.0, θ = 15.0

Input data:

```
TRANSFORM STRAIN
  2.0        .05         1.0         15.0
THEEND
```

Output:

```
STRAIN TRANSFORMATION THRU     15.   DEGREES
                        EPSLN1     EPSLN2     EPSLN6
-----------------------------------------------------
GIVEN                    2.000       .050      1.000
TRANSFORMED              2.119     -.069      -.109
-----------------------------------------------------
```

III. Modulus/Compliance Transformation

1. Transformation of modulus matrix of T300/5208 material stored in the program through 30° angle.

2. Transformation of compliance matrix of AS/3501 material stored in the program through 30° angle.

3. Transformation of modulus matrix and compliance matrix of a new material through 30° angle.

$$E_x = 190.\ \text{GPa},\quad E_y = 12.0\ \text{GPa},\ \nu_x = 0.3,\ E_s = 8.1\ \text{GPa}.$$

Input:

```
TRANSFORM MODULUS          ]  Case 1
T300/5208 ENGLISH          ]
 30.0                      ]
TRANSFORM COMPLIANCE       ]  Case 2
AS/3501   SI               ]
 30.0                      ]
TRANSFORM MODCOM
NEW       ENGLISH
   190.    12.0       0.3      8.1        30.0 ]  Case 3
THEEND
```

Output :

Case

ENGLISH UNITS
MODULUS TRANSFORMATION THRU 30. DEGREE ANGLE
(1.E+06 PSI)

MODULUS OF THE MATERIAL			TRANSFORMED MODULUS		
26.4	.4	0.0	15.9	4.7	7.9
.4	1.5	0.0	4.7	3.4	2.9
0.0	0.0	1.0	7.9	2.9	5.3

1

SI UNITS
COMPLIANCE TRANSFORMATION THRU 30. DEGREE ANGLE
(1/TPA)

COMPLIANCE OF MATERIAL			TRANSFORMED COMPLIANCE		
7.2	-2.2	0.0	36.6	-5.5	-49.0
-2.2	111.6	0.0	-5.5	88.8	-41.4
0.0	0.0	140.8	-49.0	-41.4	127.6

2

ENGLISH UNITS
MODULUS TRANSFORMATION THRU 30. DEGREE ANGLE
(1.E+06 PSI)

MODULUS OF THE MATERIAL			TRANSFORMED MODULUS		
27.7	.5	0.0	16.8	5.0	8.2
.5	1.8	0.0	5.0	3.8	3.1
0.0	0.0	1.2	8.2	3.1	5.6

3

COMPLIANCE TRANSFORMATION THRU 30. DEGREE ANGLE
(1.0E-09/PSI)

COMPLIANCE OF MATERIAL			TRANSFORMED COMPLIANCE		
36.3	-10.9	0.0	211.8	-51.9	-280.4
-10.9	574.6	0.0	-51.9	481.0	-185.8
0.0	0.0	851.2	-280.4	-185.8	687.3

IV. Effective material properties of laminates and strength of sandwich laminates:

1. Modulus matrix $\underset{\sim}{A}$ for a $(0/90)_s$ laminate - dimensional.
2. Modulus matrix $\underset{\sim}{A}^*$ for a $(0/90)_s$ laminate - normalized.
3. Compliance matrix $\underset{\sim}{a}$ for a $(0/90)_s$ laminate - dimensional.
4. Compliance matrix $\underset{\sim}{a}^*$ for a $(0/90)_s$ laminate - normalized.
5. Engineering constants for a $(0/90)_s$ laminate.
6. Strength of a sandwich laminate. One layer thickness of sandwich core is equal to the thickness of eight plies.

<u>Input:</u>

```
     LAMINATE  INPLANE
     PURE      DIMENSIONL
      MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE
(1)  T300/5208 SI
      $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
      C=0.,NLDCN=1  $
     LAMINATE  INPLANE
     PURE      NORMALIZED
      MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE
(2)  T300/5208 SI
      $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
      C=0.,NLDCN=1  $
     LAMINATE  INPLANE
     PURE                DIMENSIONL
      COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE
(3)  T300/5208 SI
      $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
      C=0.,NLDCN=1  $
     LAMINATE  INPLANE
     PURE                NORMALIZED
      COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE
(4)  T300/5208 SI
      $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
      C=0.,NLDCN=1  $
     LAMINATE  INPLANE
     PURE      ENGCONST
      ENGINEERING CONSTANTS FOR (0/90)-SYM. LAMINATE
(5)  T300/5208 SI
      $LAYER NNL=4,TH=0.,2*90.,0.,PLNM=4*1.,DT=0.,
      C=0.,NLDCN=1  $
     LAMINATE  INPLANE
     HYBRID                        STRENGTH
       STRENGTH OF (0/0/90/90/4CORE)-SYMM. LAMI. TSAI-WU FXYS=-.5
(6)   $LAYERS NNL=5,LMPI=2*1,6,2*1,TH=0.,90.,0.,90.,0.,
      PLNM=2*2.,1.,2*2.,IUNIT=1,DT=0.,C=0.,NLDCN=1  $
     TSAI WU   STRESS                            -0.5
      $STRESS AN=1.,0.,0.,AM=3*0.  $
     THEEND
```

Output:

```
 -------------------------------------------------------------------------
MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE                                    1
 -------------------------------------------------------------------------
   NUMBER OF PLYS =  4
   ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
     0.0 90.0 90.0  0.0
   NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
     1.0  1.0  1.0  1.0
   MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
      1    1    1    1
   TEMPERATURE DT=    0.0000    MOISTURE=    0.0000
                 SI UNITS
 -------------------------------------------------------------------------
                                             A    B


                                             B    D
 -------------------------------------------------------------------------
  .480E+08    .145E+07   0.             .291E-10   0.           0.
  .145E+07    .480E+08   0.            0.           .637E-11    0.
 0.          0.            .358E+07    0.          0.             .909E-12
  .291E-10   0.           0.            .167E+01    .302E-01    0.
 0.           .637E-11   0.             .302E-01    .331E+00    0.
 0.          0.            .909E-12    0.          0.             .747E-01
 -------------------------------------------------------------------------


 -------------------------------------------------------------------------
MODULUS MATRIX FOR (0/90)-SYMM. LAMINATE                                    2
 -------------------------------------------------------------------------
   NUMBER OF PLYS =  4
   ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
     0.0 90.0 90.0  0.0
   NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
     1.0  1.0  1.0  1.0
   MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
      1    1    1    1
   TEMPERATURE DT=    0.0000    MOISTURE=    0.0000
                 SI UNITS
 -------------------------------------------------------------------------
                                              A#    B#


                                             3B#    D#       GPA
 -------------------------------------------------------------------------
     96.1        2.9        0.0         .0        0.0        0.0
      2.9       96.1        0.0        0.0         .0        0.0
      0.0        0.0        7.2        0.0        0.0         .0
       .0        0.0        0.0      160.4        2.9        0.0
      0.0         .0        0.0        2.9       31.8        0.0
      0.0        0.0         .0        0.0        0.0        7.2
 -------------------------------------------------------------------------
```

```
------------------------------------------------------------------
COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE                          3
------------------------------------------------------------------
   NUMBER OF PLYS =   4
   ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
     0.0 90.0 90.0  0.0
   NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
     1.0  1.0  1.0  1.0
   MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
       1     1     1     1
   TEMPERATURE DT=     0.0000     MOISTURE=     0.0000
                  SI UNITS
------------------------------------------------------------------
------------------------------------------------------------------
                                             ALPHA     BETA


                                             TRSBTA    DELTA
------------------------------------------------------------------
  .208E-07  -.628E-09  0.             -.364E-18   .452E-19  0.
 -.628E-09   .208E-07  0.              .182E-19  -.402E-18  0.
 0.         0.          .279E-06  0.            0.          -.340E-17
 -.364E-18   .182E-19  0.              .600E+00  -.547E-01  0.
  .452E-19  -.402E-18  0.             -.547E-01   .303E+01  0.
 0.         0.         -.340E-17  0.            0.           .134E+02
   NONMECH. STRESS AND MOMENT RESULTANTS N,M
                 0.              0.              0.
                 0.              0.              0.
==================================================================
COMPLIANCE MATRIX FOR (0/90)-SYM. LAMINATE                          4
------------------------------------------------------------------
   NUMBER OF PLYS =   4
   ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
     0.0 90.0 90.0  0.0
   NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
     1.0  1.0  1.0  1.0
   MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
       1     1     1     1
   TEMPERATURE DT=     0.0000     MOISTURE=     0.0000
                  SI UNITS
------------------------------------------------------------------
                                              ALPHA#    BETA#/3


                                              TRSBTA#   DELTA#      (1./TPA)
------------------------------------------------------------------
      10.4        -.3        0.0        -.0         .0        0.0
       -.3       10.4        0.0         .0        -.0        0.0
       0.0        0.0      139.5        0.0        0.0        -.0
       -.0         .0        0.0        6.2        -.6        0.0
        .0        -.0        0.0        -.6       31.5        0.0
       0.0        0.0        -.0        0.0        0.0      139.5
   NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#
                 0.              0.              0.
                 0.              0.              0.
------------------------------------------------------------------
```

```
-----------------------------------------------------------------
ENGINEERING CONSTANTS FOR (0/90)-SYM. LAMINATE                      (5)
-----------------------------------------------------------------
   NUMBER OF PLYS =  4
   ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
     0.0 90.0 90.0  0.0
   NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
     1.0  1.0  1.0  1.0
   MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
       1    1    1    1
   TEMPERATURE DT=    0.0000    MOISTURE=    0.0000
                 SI UNITS
-----------------------------------------------------------------
   SOME ENGINEERING CONSTANTS, ES IN GPA
   INPLANE :, E1= 95.991  E2= 95.991  V21=   .030  E6=  7.170
   FLEXURAL:,EF1=160.114 EF2= 31.727 VF21=   .091 EF6=  7.170
```

```
--------------------------------------------------------------------------------
STRENGTH OF (0/0/90/90/4CORE)-SYMM. LAMI. TSAI-WU FXYS=-.5
--------------------------------------------------------------------------------
 NUMBER OF PLYS =  5
 ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
   0.0 90.0  0.0 90.0  0.0
 NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
   2.0  2.0  1.0  2.0  2.0
 MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
     1    1    6    1    1
 TEMPERATURE DT=     0.0000    MOISTURE=     0.0000
               SI UNITS
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------
 APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M
               1.000               0.000               0.000
               0.000               0.000               0.000
--------------------------------------------------------------------------------
EFFECTIVE NONMECHANICAL STRAIN COMP.
           0.                  0.                  0.
--------------------------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =  0.0
MECH/NONMECH    LOWER SURF.     UPPER SURF.
  MECH.              1               2
  NONMECH.           3               4
--------------------------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------------------------
         1        .104E-07        -.314E-09        0.
         2        .104E-07        -.314E-09        0.
         3       0.               0.               0.
         4       0.               0.               0.
--------------------------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------------------------
         1        .189E+04         .269E+02        0.
         2        .189E+04         .269E+02        0.
         3       0.               0.               0.
         4       0.               0.               0.
--------------------------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .682E+06  UPPER SURF.=  .682E+06
STRENGTH R# MPA : LOWER SURF.=  340.941   UPPER SURF.=  340.941
--------------------------------------------------------------------------------


EFFECTIVE NONMECHANICAL STRAIN COMP.
           0.                  0.                  0.
```

```
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
        1        -.314E-09        .104E-07        0.
        2        -.314E-09        .104E-07        0.
        3        0.              0.               0.
        4        0.              0.               0.
--------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------
        1        -.269E+02        .107E+03        0.
        2        -.269E+02        .107E+03        0.
        3        0.              0.               0.
        4        0.              0.               0.
--------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .373E+06  UPPER SURF.=  .373E+06
STRENGTH R# MPA : LOWER SURF.=   186.698  UPPER SURF.=   186.698
--------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
            0.               0.               0.
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
        1        -.314E-09        .104E-07        0.
        2        -.314E-09        .104E-07        0.
        3        0.              0.               0.
        4        0.              0.               0.
--------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------
        1        -.269E+02        .107E+03        0.
        2        -.269E+02        .107E+03        0.
        3        0.              0.               0.
        4        0.              0.               0.
--------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .373E+06  UPPER SURF.=  .373E+06
STRENGTH R# MPA : LOWER SURF.=   186.698  UPPER SURF.=   186.698
--------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
                0.                0.                0.
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =  0.0
MECH/NONMECH     LOWER SURF.      UPPER SURF.
  MECH.                1                2
  NONMECH.             3                4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
        1         .104E-07        -.314E-09        0.
        2         .104E-07        -.314E-09        0.
        3        0.               0.               0.
        4        0.               0.               0.
--------------------------------------------------------------
     STRESS COMPONFNTS
--------------------------------------------------------------
        1         .189E+04         .269E+02        0.
        2         .189E+04         .269E+02        0.
        3        0.               0.               0.
        4        0.               0.               0.
--------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRFNGTH RATIO R: LOWER SURF.=  .682F+06  UPPER SURF.=  .682E+06
STRENGTH R# MPA : LOWER SURF.=   340.941  UPPER SURF.=   340.941
--------------------------------------------------------------
```

V. Unsymmetric Laminates:

Replace the properties of first two materials by new material properties, calculate the effective modulus matrices and engineering constants and conduct the strength analysis of two unsymmetric laminates in the presence of curing stress

1. Laminate (30/-30/30/-30/90/90) total.

2. Laminate (0/90/45/-45) total.

Input data:

```
 NEWMTRLS  SI
  $LAMDATA NNM=2,EX=113.08,137.9,EY=9.24,11.03,VX=2*.3,
  ES=2*5.86,ALFX=2*-.9,ALFY=2*23.04,BTAX=2*0.,BTAY=2*0.,
  X=2*1448.,XD=1448.,Y=2*51.7,YD=2*207,S=2*93,SH=.000125  $
 LAMINATE  GENERAL
 PURE      ALL       BOTH      STRENGTH
  (30/-30/30/-30/90/90)-TOTAL LAMINATE
(1) T300/5208 ENGLISH
  $LAYER NNL=6,TH=2*90.,-30.,30.,-30.,30.,PLNM=6*1.,DT=-175.,
  C=0.,NLDCN=1  $
 TSAI WU                                  -0.5
  $STRESS AN=1.,2*0.,AM=3*0.  $
 LAMINATE  GENERAL
 PURE      ALL       BOTH      STRENGTH
   (0/90/45/-45)-TOTAL LAMINATE
 T300/5208 ENGLISH
(2) $LAYER NNL=4,TH=-45.,45.,90.,0.,PLNM=4*1.,DT=-175.,
  C=0.,NLDCN=1  $
 TSAI WU                                  -0.5
  $STRESS AN=1.,2*0.,AM=3*0.  $
 THEEND
```

Note: The stacking sequence is such that the bottom ply corresponds to TH(1) in the input data card "$LAYER", where as in customary notation symbols $(0/90/\pm45)_T$, 0 denotes top ply angle and -45 denotes bottom ply.

Output:

(30/-30/30/-30/90/90)-TOTAL LAMINATE (1)

NUMBER OF PLYS = 6
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
90.0 90.0-30.0 30.0-30.0 30.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 1.0 1.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 1 1 1 1
TEMPERATURE DT= -175.0000 MOISTURE= 0.0000
ENGLISH UNITS

A B

B D

.214E+06	.624E+05	0.	.855E+03	.249E+03	.231E+03
.624E+05	.214E+06	0.	.249E+03	-.135E+04	.876E+02
0.	0.	.756E+05	.231E+03	.876E+02	.249E+03
.855E+03	.249E+03	.231E+03	.127E+02	.373E+01	.228E+01
.249E+03	-.135E+04	.876E+02	.373E+01	.200E+02	.863E+00
.231E+03	.876E+02	.249E+03	.228E+01	.863E+00	.468E+01

A# B#

3B# D# 1.E+06 PSI

7.2	2.1	0.0	2.0	.6	.5
2.1	7.2	0.0	.6	-3.1	.2
0.0	0.0	2.6	.5	.2	.6
5.9	1.7	1.6	5.9	1.7	1.1
1.7	-9.3	.6	1.7	9.3	.4
1.6	.6	1.7	1.1	.4	2.2

SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI
INPLANE :, E1= 6.611 E2= 6.611 V21= .292 E6= 2.558
FLEXURAL:,EF1= 5.151 EF2= 8.782 VF21= .167 EF6= 1.988

ALPHA BETA

TRSBTA DELTA

.767E-05	-.328E-05	.210E-05	-.382E-03	-.247E-03	-.198E-03
-.328E-05	.114E-04	.493E-07	-.238E-03	.862E-03	-.973E-04
.210E-05	.493E-07	.170E-04	-.295E-03	-.505E-05	-.861E-03
-.382E-03	-.238E-03	-.295E-03	.127E+00	-.330E-01	-.166E-01
-.247E-03	.862E-03	-.505E-05	-.330E-01	.118E+00	-.937E-02
-.198E-03	-.973E-04	-.861E-03	-.166E-01	-.937E-02	.281E+00

NONMECH. STRESS AND MOMENT RESULTANTS N,M

-.362E+02	-.362E+02	.119E-11
.257E+00	-.257E+00	.741E-01

```
-------------------------------------------------------------------
                                  ALPHA#     BETA#/3

                                  TRSBTA#    DELTA#       1.0E-09/PSI
-------------------------------------------------------------------
  226.7       -96.9        62.2      -55.6      -35.9      -28.8
  -96.9       337.3         1.5      -34.7      125.4      -14.2
   62.2         1.5       501.5      -42.9        -.7     -125.3
 -166.8      -104.0      -128.8      272.7      -71.0      -35.7
 -107.8       376.3        -2.2      -71.0      253.8      -20.1
  -86.3       -42.5      -375.9      -35.7      -20.1      603.3
 NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#
            -.123E+04          -.123E+04          .404E-10
             .176E+04          -.176E+04          .509E+03
-------------------------------------------------------------------
-------------------------------------------------------------------
 APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M
               1.000              0.000              0.000
               0.000              0.000              0.000
-------------------------------------------------------------------
EFFECTIVE NONMECHANICAL STRAIN COMP.
            -.113E-02          .328E-03          -.654E-03
-------------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0
MECH/NONMECH     LOWER SURF.      UPPER SURF.
  MECH.                 1                2
  NONMECH.              3                4
-------------------------------------------------------------------
     STRAIN COMPONENTS
-------------------------------------------------------------------
         1        .367E-06        .133E-04        -.503E-05
         2       -.848E-06        .114E-04        -.405E-05
         3        .240E-03        .111E-02         .654E-03
         4       -.636E-04        .142E-02         .508E-03
-------------------------------------------------------------------
     STRESS COMPONENTS
-------------------------------------------------------------------
         1        .115E+02        .181E+02        -.427E+01
         2       -.939E+01        .151E+02        -.344E+01
         3        .442E+04        .160E+04         .556E+03
         4       -.476E+03        .189E+04         .432E+03
-------------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .330E+03  UPPER SURF.=  .366E+03
STRENGTH R# KSI : LOWER SURF.=    11.174  UPPER SURF.=    12.396
-------------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
            -.821E-03          .239E-04          -.508E-03
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.                1                2
  NONMECH.             3                4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
          1       -.848E-06        .114E-04        -.405E-05
          2       -.206E-05        .955E-05        -.308E-05
          3       -.636E-04        .142E-02         .508E-03
          4       -.368E-03        .173E-02         .362E-03
--------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------
          1       -.939E+01        .151E+02        -.344E+01
          2       -.302E+02        .121E+02        -.262E+01
          3       -.476E+03        .189E+04         .432E+03
          4       -.537E+04        .218E+04         .308E+03
--------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .366E+03  UPPER SURF.=  .415E+03
STRENGTH R# KSI : LOWER SURF.=    12.396  UPPER SURF.=    14.048
--------------------------------------------------------------


EFFECTIVE NONMECHANICAL STRAIN COMP.
            -.515E-03         -.280E-03          -.362E-03
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =-30.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.                1                2
  NONMECH.             3                4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
          1        .532E-05        .217E-05         .116E-04
          2        .402E-05        .369E-06         .105E-04
          3       -.387E-03        .174E-02        -.384E-03
          4       -.296E-03        .166E-02         .217E-03
--------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------
          1        .887E+02        .509E+01         .986E+01
          2        .666E+02        .213E+01         .896E+01
          3       -.569E+04        .220E+04        -.327E+03
          4       -.422E+04        .212E+04         .185E+03
--------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .747E+03  UPPER SURF.=  .103E+04
STRENGTH R# KSI : LOWER SURF.=    25.278  UPPER SURF.=    34.700
--------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
             -.208E-03        -.584E-03        -.216E-03
---------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 30.0
MECH/NONMECH    LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
---------------------------------------------------------------
     STRAIN COMPONENTS
---------------------------------------------------------------
        1       .584E-05        -.145E-05        -.843E-05
        2       .371E-05        -.241E-05        -.834E-05
        3      -.483E-03         .184E-02        -.433E-03
        4      -.266E-03         .163E-02        -.889E-03
---------------------------------------------------------------
     STRESS COMPONENTS
---------------------------------------------------------------
        1       .960E+02         .405E+00        -.717E+01
        2       .603E+02        -.176E+01        -.709E+01
        3      -.724E+04         .229E+04        -.368E+03
        4      -.374E+04         .209E+04        -.756E+03
---------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .127E+04  UPPER SURF.=  .164E+04
STRENGTH R# KSI : LOWER SURF.=    42.843  UPPER SURF.=    55.621
---------------------------------------------------------------


EFFECTIVE NONMECHANICAL STRAIN COMP.
              .983E-04        -.888E-03        -.703E-04
---------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =-30.0
MECH/NONMECH    LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
---------------------------------------------------------------
     STRAIN COMPONENTS
---------------------------------------------------------------
        1       .273E-05        -.144E-05         .947E-05
        2       .144E-05        -.324E-05         .841E-05
        3      -.205E-03         .157E-02         .819E-03
        4      -.115E-03         .148E-02         .142E-02
---------------------------------------------------------------
     STRESS COMPONENTS
---------------------------------------------------------------
        1       .445E+02        -.832E+00         .805E+01
        2       .224E+02        -.379E+01         .715E+01
        3      -.276E+04         .203E+04         .696E+03
        4      -.129E+04         .195E+04         .121E+04
---------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .145E+04  UPPER SURF.=  .198E+04
STRENGTH R# KSI : LOWER SURF.=    49.147  UPPER SURF.=    67.112
---------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
              .405E-03          -.119E-02          .755E-04
----------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 30.0
MECH/NONMECH     LOWER SURF.      UPPER SURF.
  MECH.                1               2
  NONMECH.             3               4
----------------------------------------------------------------
     STRAIN COMPONENTS
----------------------------------------------------------------
        1         .157E-05        -.337E-05        -.825E-05
        2        -.565E-06        -.434E-05        -.817E-05
        3        -.492E-04         .141E-02        -.135E-02
        4         .168E-03         .120E-02        -.180E-02
----------------------------------------------------------------
     STRESS COMPONENTS
----------------------------------------------------------------
        1         .246E+02        -.392E+01        -.702E+01
        2        -.111E+02        -.608E+01        -.694E+01
        3        -.240E+03         .189E+04        -.114E+04
        4         .326E+04         .169E+04        -.153E+04
----------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .202E+04  UPPER SURF.=  .226E+04
STRENGTH R# KSI : LOWER SURF.=    68.433  UPPER SURF.=    76.599
----------------------------------------------------------------
```

(0/90/45/-45)-TOTAL LAMINATE

NUMBER OF PLYS = 4
ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
-45.0 45.0 90.0 0.0
NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
1.0 1.0 1.0 1.0
MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
1 1 1 1
TEMPERATURE DT= -175.0000 MOISTURE= 0.0000
ENGLISH UNITS

A B

B D

.142E+06	.416E+05	-.582E-09	.350E+03	-.166E+03	.920E+02
.416E+05	.142E+06	.582E-09	-.166E+03	-.183E+02	.920E+02
-.582E-09	.582E-09	.504E+05	.920E+02	.920E+02	-.166E+03
.350E+03	-.166E+03	.920E+02	.642E+01	.135E+01	-.906E+00
-.166E+03	-.183E+02	.920E+02	.135E+01	.279E+01	-.906E+00
.920E+02	.920E+02	-.166E+03	-.906E+00	-.906E+00	.135E+01

A# B#

3B# D# 1.E+06 PSI

7.2	2.1	-.0	1.8	-.9	.5
2.1	7.2	.0	-.9	-.1	.5
-.0	.0	2.6	.5	.5	-.9
5.4	-2.6	1.4	10.1	2.1	-1.4
-2.6	-.3	1.4	2.1	4.4	-1.4
1.4	1.4	-2.6	-1.4	-1.4	2.6

SOME ENGINEERING CONSTANTS, ES IN 1.E+06 PSI
INPLANE :, E1= 6.611 E2= 6.611 V21= .292 E6= 2.558
FLEXURAL:,EF1= 8.796 EF2= 3.404 VF21= .368 EF6= 2.036

ALPHA BETA

TRSBTA DELTA

.128E-04	-.444E-05	-.233E-05	-.111E-02	.111E-02	-.709E-03
-.444E-05	.916E-05	-.132E-05	.558E-03	-.559E-03	-.401E-03
-.233E-05	-.132E-05	.308E-04	.155E-03	-.153E-03	.334E-02
-.111E-02	.558E-03	.155E-03	.279E+00	-.166E+00	.110E+00
.111E-02	-.559E-03	-.153E-03	-.166E+00	.562E+00	.173E+00
-.709E-03	-.401E-03	.334E-02	.110E+00	.173E+00	.117E+01

NONMECH. STRESS AND MOMENT RESULTANTS N,M

-.241E+02	-.241E+02	.587E-12
.428E-01	-.428E-01	.428E-01

			ALPHA#	BETA#/3	
			TRSBTA#	DELTA#	1.0E-09/PSI
252.3	-87.4	-46.0	-72.0	72.0	-45.9
-87.4	180.4	-25.9	36.1	-36.1	-25.9
-46.0	-25.9	607.5	10.0	-9.9	216.2
-215.9	108.2	30.1	177.8	-106.0	70.0
216.1	-108.4	-29.7	-106.0	358.0	110.2
-137.6	-77.8	648.6	70.0	110.2	747.7

NONMECH. EFFECTIVE STRESS AND MOMENT N#,M#

-.123E+04	-.123E+04	.298E-10
.661E+03	-.661E+03	.661E+03

APPLIED MECHANICAL STRESS AND MOMENT RESULTANTS N,M

1.000	0.000	0.000
0.000	0.000	0.000

EFFECTIVE NONMECHANICAL STRAIN COMP.

-.693E-03	.283E-03	-.487E-03

ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =-45.0

MECH/NONMECH	LOWER SURF.	UPPER SURF.
MECH.	1	2
NONMECH.	3	4

STRAIN COMPONENTS

1	.185E-05	.651E-05	.392E-04
2	.360E-05	.476E-05	.282E-04
3	-.492E-04	.179E-02	-.976E-03
4	-.232E-03	.197E-02	-.610E-03

STRESS COMPONENTS

1	.333E+02	.953E+01	.333E+02
2	.615E+02	.789E+01	.240E+02
3	-.878E+02	.240E+04	-.830E+03
4	-.304E+04	.257E+04	-.519E+03

TSAI WU FAILURE CRITERIA

STRENGTH RATIO R: LOWER SURF.= .279E+03 UPPER SURF.= .357E+03

STRENGTH R# KSI : LOWER SURF.= 14.160 UPPER SURF.= 18.138

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
          -.511E-03       .996E-04       -.122E-03
-------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 45.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
-------------------------------------------------------------
     STRAIN COMPONENTS
-------------------------------------------------------------
        1       .476E-05        .360E-05        -.282E-04
        2       .302E-05        .535E-05        -.172E-04
        3      -.354E-03        .210E-02         .610E-03
        4      -.171E-03        .191E-02         .244E-03
-------------------------------------------------------------
     STRESS COMPONENTS
-------------------------------------------------------------
        1       .801E+02        .679E+01        -.240E+02
        2       .520E+02        .845E+01        -.147E+02
        3      -.500E+04        .269E+04         .519E+03
        4      -.205E+04        .251E+04         .208E+03
-------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .371E+03  UPPER SURF.=  .450E+03
STRENGTH R# KSI : LOWER SURF.=    18.835  UPPER SURF.=    22.828
-------------------------------------------------------------


EFFECTIVE NONMECHANICAL STRAIN COMP.
          -.328E-03      -.833E-04        .244E-03
-------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. = 90.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.               1               2
  NONMECH.            3               4
-------------------------------------------------------------
     STRAIN COMPONENTS
-------------------------------------------------------------
        1      -.444E-05        .128E-04         .233E-05
        2       .105E-05        .733E-05         .583E-05
        3      -.171E-03        .191E-02        -.244E-03
        4      -.354E-03        .210E-02        -.610E-03
-------------------------------------------------------------
     STRESS COMPONENTS
-------------------------------------------------------------
        1      -.681E+02        .155E+02         .198E+01
        2       .203E+02        .103E+02         .495E+01
        3      -.205E+04        .251E+04        -.208E+03
        4      -.500E+04        .269E+04        -.519E+03
-------------------------------------------------------------
TSAI WU   FAILURE CRITERIA
STRENGTH RATIO R: LOWER SURF.=  .297E+03  UPPER SURF.=  .462E+03
STRENGTH R# KSI : LOWER SURF.=    15.095  UPPER SURF.=    23.466
-------------------------------------------------------------
```

```
EFFECTIVE NONMECHANICAL STRAIN COMP.
            -.145E-03          -.266E-03          .610E-03
--------------------------------------------------------------
ON AXIS STRAIN /STRESS COMPONENTS: PLY ORIEN. =  0.0
MECH/NONMECH     LOWER SURF.     UPPER SURF.
  MECH.              1               2
  NONMECH.           3               4
--------------------------------------------------------------
     STRAIN COMPONENTS
--------------------------------------------------------------
        1         .733E-05         .105E-05         -.583E-05
        2         .185E-05         .653E-05         -.932E-05
        3        -.232E-03         .197E-02          .610E-03
        4        -.492E-04         .179E-02          .976E-03
--------------------------------------------------------------
     STRESS COMPONENTS
--------------------------------------------------------------
        1         .121E+03         .438E+01         -.495E+01
        2         .332E+02         .957E+01         -.792E+01
        3        -.304E+04         .257E+04          .519E+03
        4        -.878E+02         .240E+04          .830E+03
--------------------------------------------------------------
TSAI WU   FAILURE CPITERIA
STRENGTH RATIO R: LOWER SURF.=  .934E+03  UPPER SURF.=  .517E+03
STRENGTH R# KSI : LOWER SURF.=    47.422  UPPER SURF.=    26.242
--------------------------------------------------------------
```

VI. Engineering constants plot:

To replace material properties of the first two materials in the program and use the first material to compute effective modulus matrices for $(0/90/0_4)_s$ laminate, and plot engineering constants for $(0/90/\pm\ \phi_2)_s$ laminates, ϕ varies from 0° to 90°.

Input data:

```
NEWMTRLS
 $LAMDATA NNM=2,EX=185.,220.,EY=11.2,10.5,VX=0.29,0.31,
 ALFX=12.5,11.,ALFY=-.5,-.3,BTAX=2*0.,BTAY=2*0.,X=1400.,
 1300.,XD=1400.,1300.,Y=35.,32,YD=230.,210.,S=2*75.,SH=2*.125E-3   $
LAMINATE  INPLANE
PURE       DIMENSIONL              PLTONE     ENGCPLT
PLOT FOR ENGINEERING CONSTANTS OF  (0/90/F2/-F2) -
T300/5208 SI
 $LAYER NNL=8,TH=0.,90.,0.,0.,0.,0.,90.,0.,PLNM=2*1.,4*2.,
 2*1.,DT=0.,C=0.,NLDCN=1  $
THEEND
```

Output:

```
   ------------------------------------------------------------------

PLOT FOR ENGINEERING CONSTANTS OF (0/90/F2/-F2)S -LAMINATE
   ------------------------------------------------------------------
      NUMBER OF PLYS =  8
      ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
        0.0 90.0  0.0   0.0   0.0   0.0 90.0   0.0
      NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
        1.0  1.0  2.0  2.0  2.0  2.0  1.0  1.0
      MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
          1    1    1    1    1    1    1    1
      TEMPERATURE DT=      0.0000      MOISTURE=      0.0000
                    SI UNITS
   ------------------------------------------------------------------
                                  A    B


                                  B    D
   ------------------------------------------------------------------
   .235E+09   .490E+07  0.          .407E-09   .546E-11  0.
   .490E+07   .606E+08  0.          .546E-11   .116E-09  0.
  0.         0.         .108E+08  0.         0.          .182E-10
   .407E-09   .546E-11  0.          .384E+02   .918E+00  0.
   .546E-11   .116E-09  0.          .918E+00   .170E+02  0.
  0.         0.         .182E-10  0.         0.          .202E+01
   ------------------------------------------------------------------
        PLOTS FOR ENGINEERING CONSTANTS DRAWN
```

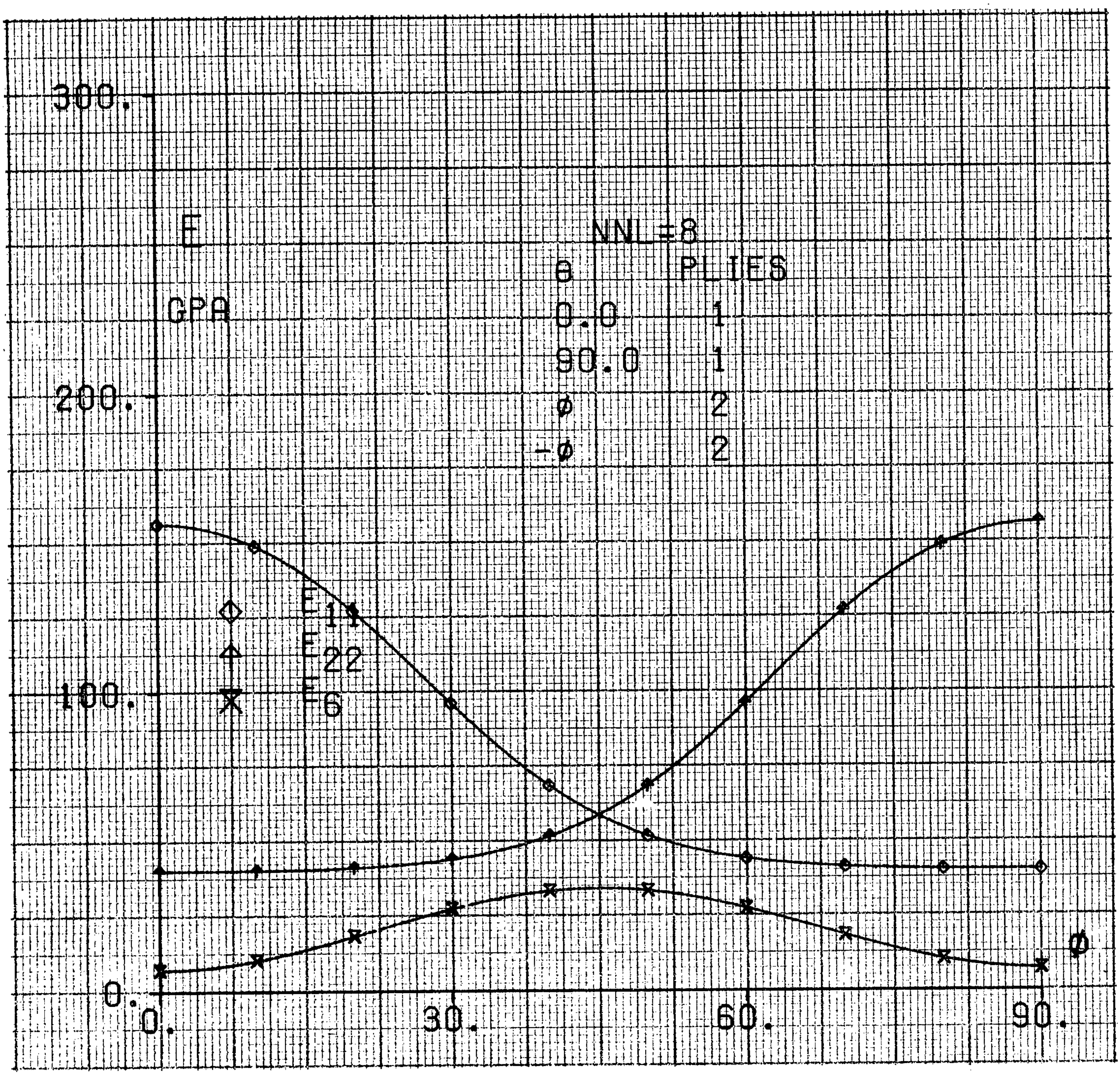


Figure A-1: Effective Engineering Constants for $(0/90/\pm\phi_2)_s$ - Laminates, ϕ Varies from 0° to 90°.

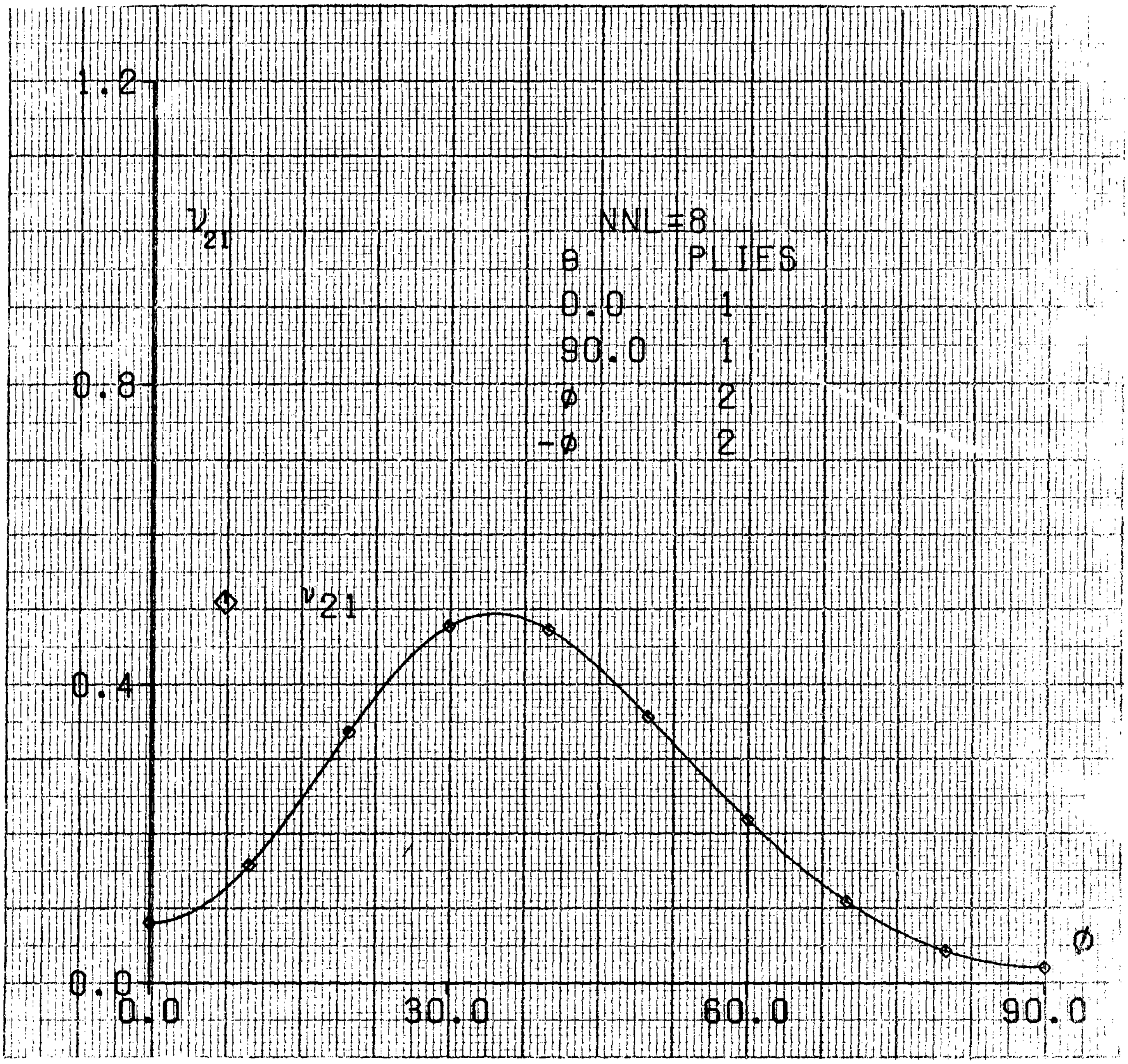


Figure A-2: Effective Poisson's Ratio ν_{21} for $(0/90/\pm\phi_2)_s$ Laminates, ϕ Varies from 0° to 90°.

VII. Failure envelopes for a pure or hybrid symmetric laminate on the basis of Tsai Wu failure criteria in strain space, $F^*_{xy} = -.5$.

1. $(0/90/\pm30)_s$ pure T300/5208 laminate.

2. $(0/90/\pm30)_s$ hybrid laminate 0° and 90° plies T300/5208 and $\pm30°$ plies KEVLAR 49.

Input data:

```
    LAMINATE  INPLANE
    PURE                                    STRNGTHPLTPLTSTART
     (0/90/30/-30) SYMMETRIC  LAMINATE FAILURE SURFACE TSAI WU FSXY=-1./2.
(1) T300/5208
     $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,PLNM=8*1.,
     DT=0.,C=0.,NLDCN=1  $
    TSAI WU   STRAIN                                  -0.5
    LAMINATE  INPLANE
    HYBRID                                  STRNGTHPLTPLTEND
(2)  (0/90/30/-30) SYM. LAMINATE FAIL. ENVELOPES TSAI WU FSXY=-1/2. HYBRID.
     $LAYERS NNL=8,LMPI=2*1,4*5,2*1,TH=0.,90.,30.,2*-30.,30.,90.,0.,
     PLNM=8*1., IUNIT= 1, DT=0., C=0, NLDCN=1  $
    TSAI WU   STRAIN                                   -0.5
    THEEND
```

Output: (1)

```
     -----------------------------------------------------------------

     (0/90/30/-30) SYMMETRIC  LAMINATE FAILURE SURFACE TSAI WU FSXY=-1./2.
     -----------------------------------------------------------------
       NUMBER OF PLYS =  8
       ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
          0.0 90.0 30.0-30.0-30.0 30.0 90.0  0.0
       NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
          1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
       MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
           1    1    1    1    1    1    1    1
       TEMPERATURE DT=    0.0000    MOISTURE=    0.0000
                        SI UNITS
     -----------------------------------------------------------------
     FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED
```

Note: LMPI in input data card number 11 represents the material property identification number of each layer in the laminate.

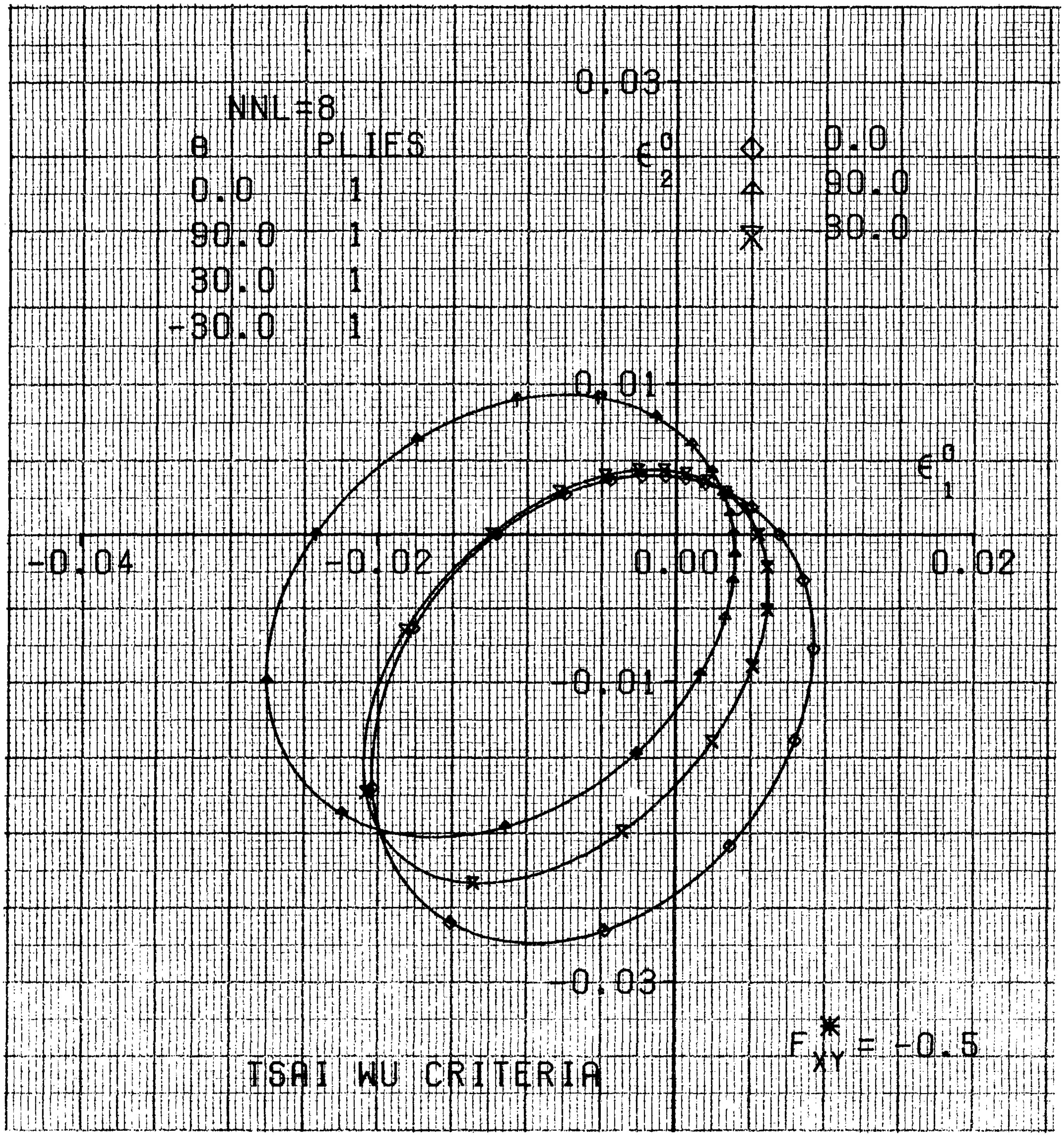


Figure A-3: Failure Envelopes for $(0/90/\pm 30)_s$ - Laminate of T300/5208 Graphite Epoxy.

```
---------------------------------------------------------------------
(0/90/30/-30) SYM. LAMINATE FAIL. ENVELOPES TSAI WU FSXY=-1/2. HYBRID.
---------------------------------------------------------------------
    NUMBER OF PLYS =  8
    ANGLES OF PLY ORIENTATION IN DEGREES, BOTTOM LAYER=1
      0.0 90.0 30.0-30.0-30.0 30.0 90.0  0.0
    NUMBER OF LAYERS FOR CORRESPONDING PLY ORIENTATION
      1.0  1.0  1.0  1.0  1.0  1.0  1.0  1.0
    MATERIAL PROPERTY IDENTIFICATION NUMBER FOR CORR. PLY
        1    1    5    5    5    5    1    1
    TEMPERATURE DT=     0.0000    MOISTURE=     0.0000
                  SI UNITS
---------------------------------------------------------------------
   FAILURE SURFACE FOR THIS LAMINATE HAS BEEN PLOTTED
```

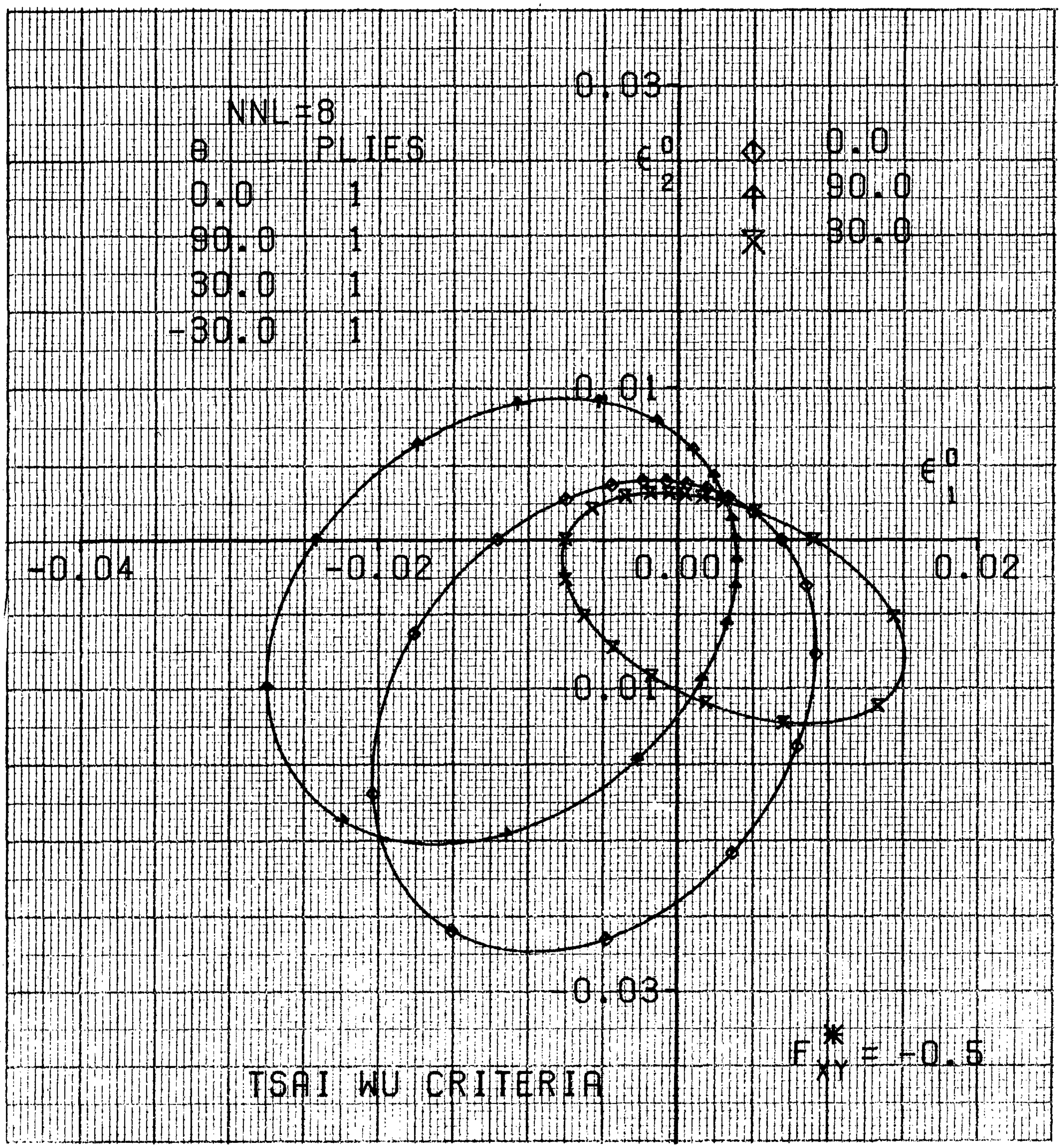


Figure A-4: Failure Envelopes for $(0/90/\pm 30)_s$ - Hybrid Laminates 0° and 90° Plies T300/5208 Material and $\pm$30° Layers Kevlar 49 Material.

VIII. Failure surfaces for different laminates in one figure: In this illustration the failure envelopes of 0° laminate on the basis of six failure theories are given for T300/5208 material, using the option of SUPERPOSE and MULTICURV.

Input data

```
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTSTART
 0 DEGREE LAMINATE T300/5208 MATERIAL TSAI WU FSXY=-.5
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRAIN              SUPERPOSE -.5       MULTICURV
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
 0 DEGREE LAMINATE T300/5208 MATERIAL CHAMIS
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
CHAMIS    STRAIN              SUPERPOSE -.7       MULTICURV
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
 0 DEGREE LAMINATE T300/5208 MATERIAL HOFFMAN
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
HOFFMAN   STRAIN              SUPERPOSE           MULTICURV
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
 0 DEGREE LAMINATE T300/5208 MATERIAL HILL CRITERIA
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
HILL      STRAIN              SUPERPOSE           MULTICURV
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
 0 DEGREE LAMINATE T300/5208 MATERIAL MAXSTRAIN CRITERIA
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
MAXSTRAIN STRAIN              SUPERPOSE           MULTICURV
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTEND
 0 DEGREE LAMINATE T300/5208 MATERIAL MAXSTRESS CRITERIA
T300/5208
 $LAYER NNL=1,TH=1*0.,PLNM=1*1.,DT=0.,C=0.,NLDCN=1  $
MAXSTRESS STRAIN              SUPERPOSE           MULTICURV
THEEND
```

Output: Figure A-5

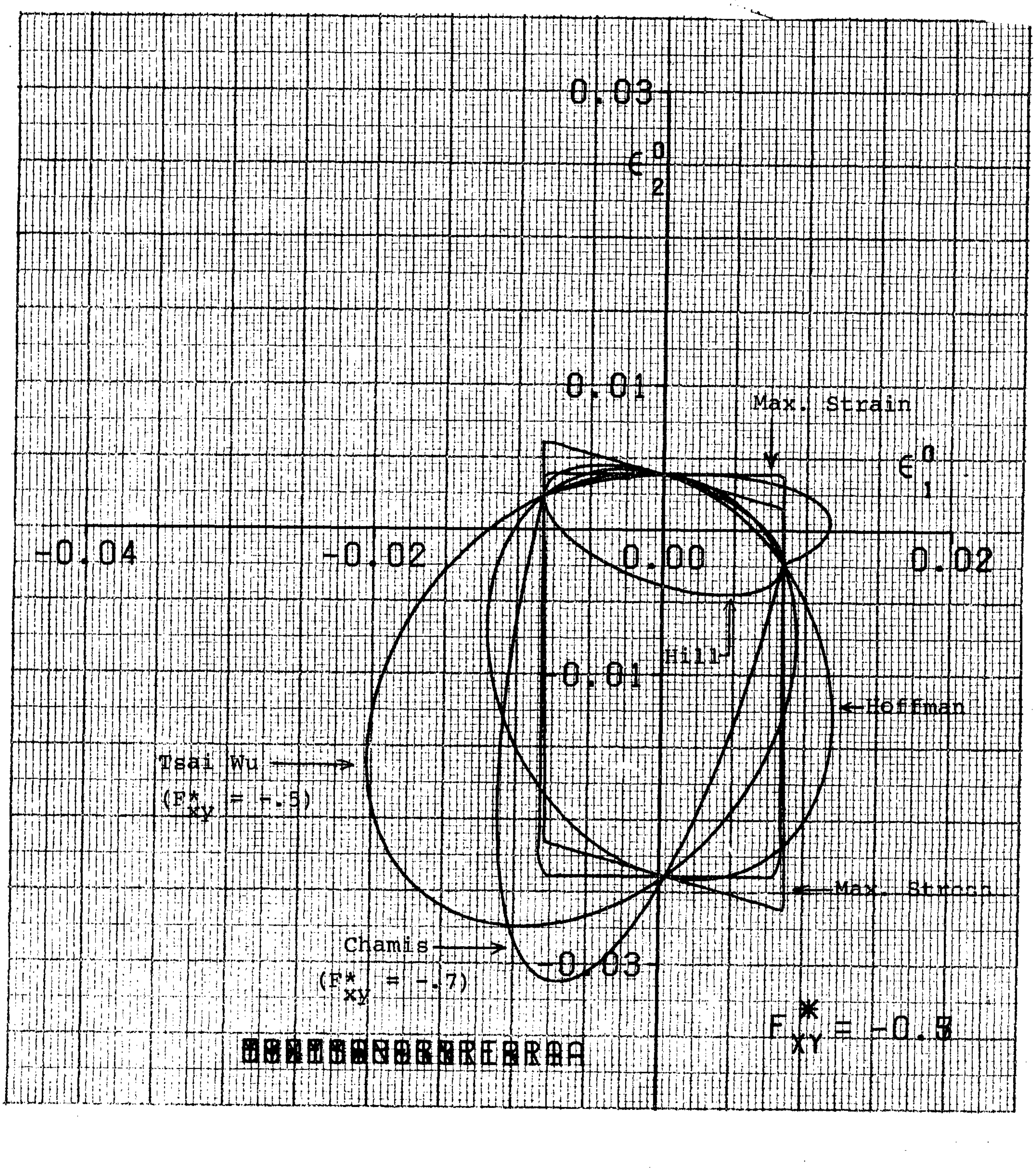


Figure A-5: Failure Envelopes for T300/5208 Unidirectional Laminate on the Basis of Different Failure Theories.

IX. Failure envelopes for $(0/90/\pm30)_s$ laminate in different spaces on the basis of Tsai Wu failure criteria, $F^*_{xy} = -.5$.

1. qr - stress space
2. qr - strain space
3. principal stress space

Input Data:

```
    LAMINATE  INPLANE
    PURE                          STRNGTHPLTPLTSTART
     (0/90/30/-30) SYMMETRIC LAMINATE TSAI WU-STRESS QR.
(1) T300/5208
     $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
     PLNM=8*1.,DT=0.,C=0.,NLDCN=1  $
    TSAI WU   STRESS    QR                      -0.5
    LAMINATE  INPLANE
    PURE                          STRNGTHPLTPLTFOLLOW
(2)  (0/90/30/-30) SYMMETRIC LAMINATE TSAI WU-STRAIN QR.
    T300/5208
     $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
     PLNM=8*1.,DT=0.,C=0.,NLDCN=1  $
    TSAI WU   STRAIN    QR                      -0.5
    LAMINATE  INPLANE
    PURE                          STRNGTHPLTPLTEND
(3)  (0/90/30/-30) SYMM. LAMINATE TSAI WU- STRESS SPACE
    T300/5208
     $LAYER NNL=8,TH=0.,90.,30.,-30.,-30.,30.,90.,0.,
     PLNM=8*1.,DT=0.,C=0.,NLDCN=1  $
    TSAI WU   STRESS                            -0.5
    THEEND
```

Output: Figures A-6 through A-8.

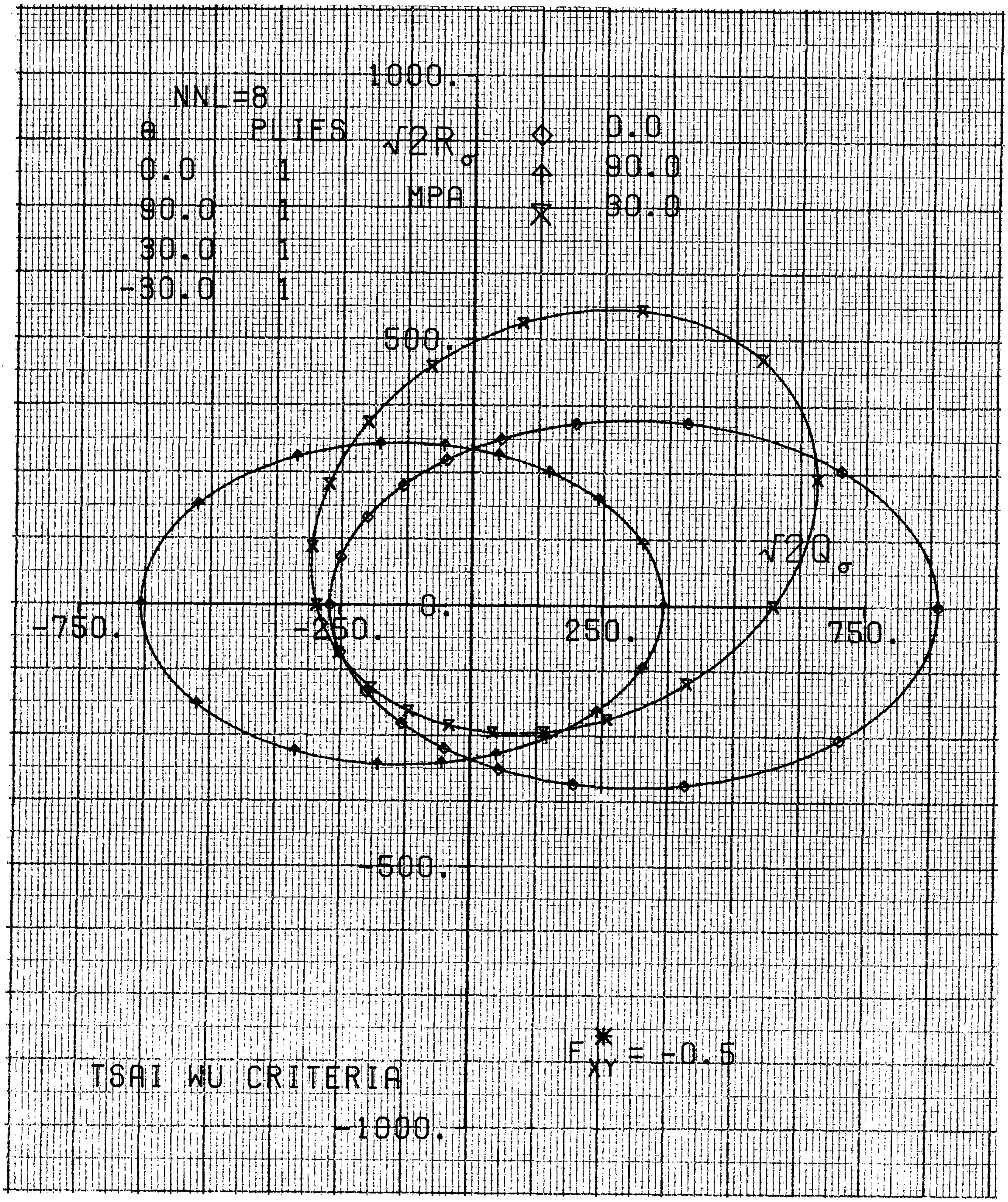


Figure A-6: Failure Envelopes for $(0/90/\pm30)_s$ Laminate in qr Plane of Stress Space.

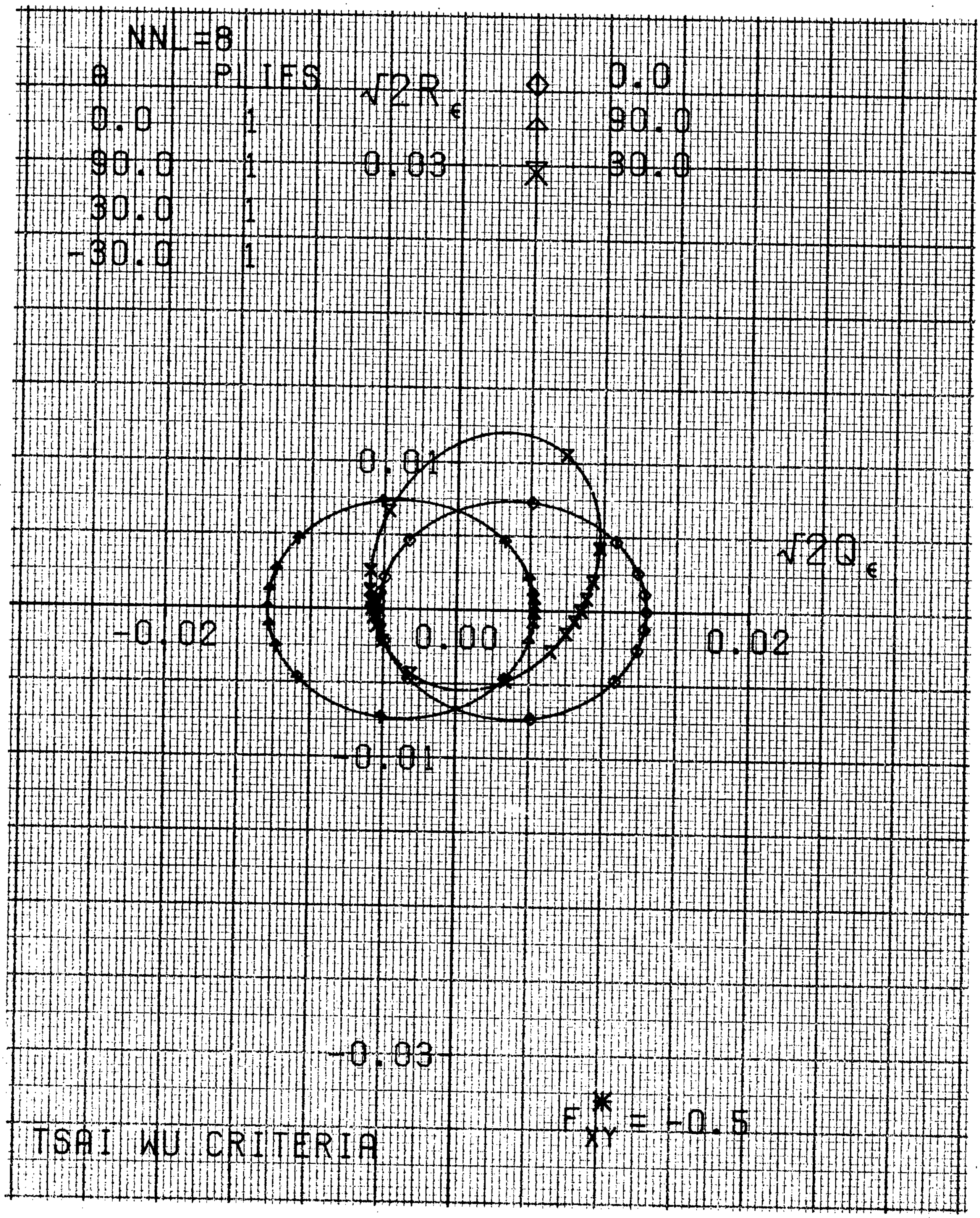


Figure A-7: Failure Envelopes for $(0/90/\underline{+}30)_s$ Laminate in qr Plane of Strain Space.

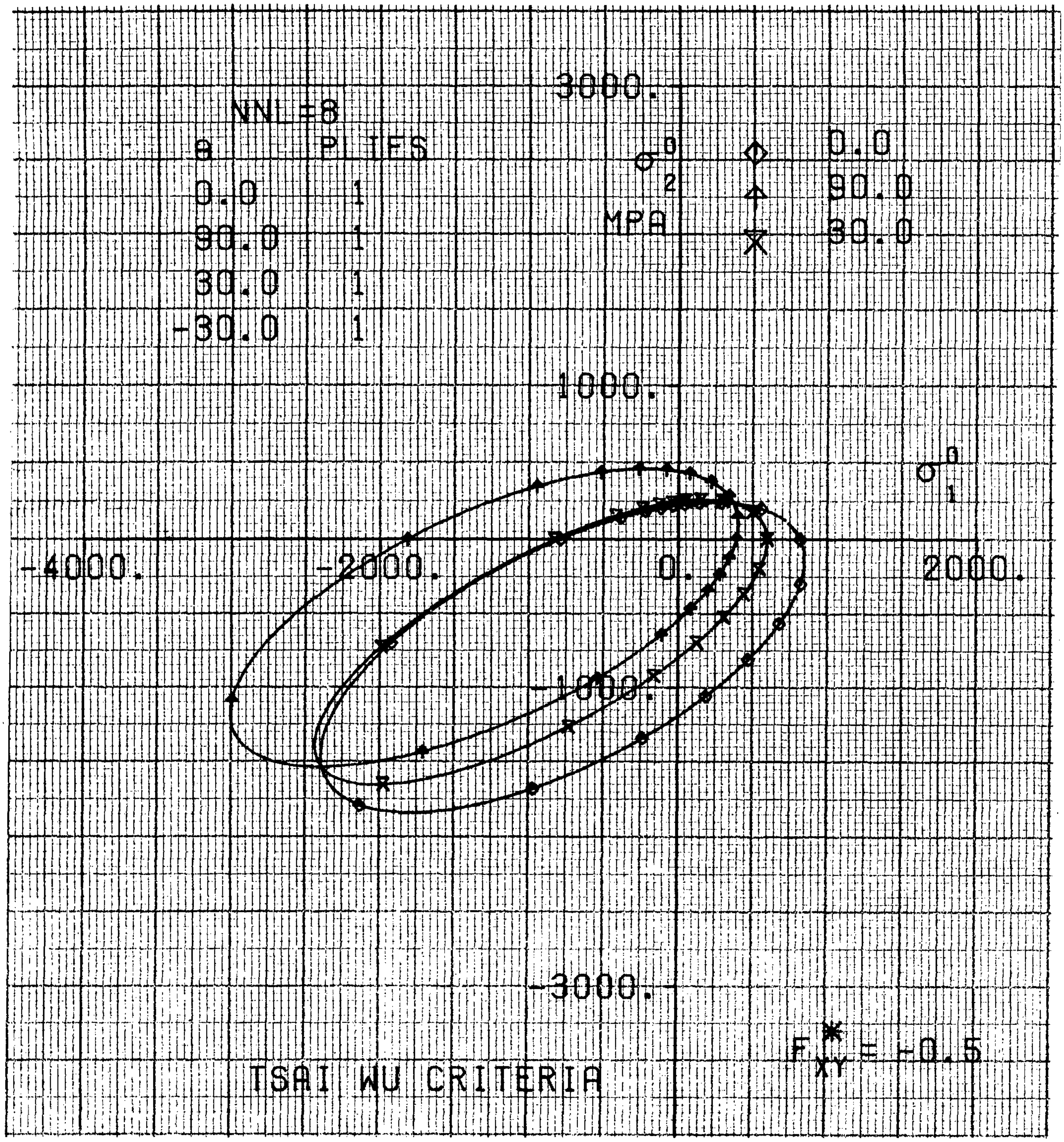


Figure A-8: Failure Envelopes for $(0/90/\pm30)_s$ - Laminate in Principal Stress Space.

X. Laminates consisting of more than three orientations:

1. Failure envelopes of 0°, 30° and 60° layers in a $(0/\underline{+}30/\underline{+}45/\underline{+}60/\underline{+}75/90)_s$ laminate.

2. Failure Envelopes of 45°, 75° and 90° layers in a $(0/\underline{+}30/\underline{+}45/\underline{+}60/\underline{+}75/90)_s$ laminate.

3. Failure envelopes of 0°, 30°, 45°, 60°, 75° and 90° layer of the aforementioned laminate.

Input data:

```
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTSTART
  (0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
 $LAYER NNL=20,TH=0.,30.,60.,45.,75.,90.,-75.,-45.,-60.,-30.,
 -30.,-60.,-45.,-75.,90.,75.,45.,60.,30.,0.,
 PLNM=20*1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRAIN                          -.5
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
  (0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
 $LAYER NNL=20,TH=45.,75.,90.,0.,30.,60.,
 -60.,-30.,-75.,-45.,-45.,-75.,-30.,-60.,60.,30.,0.,90.,75.,45.,
 PLNM=20*1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRAIN                          -.5
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTEND
  (0/30/60/45/75/90/-75/-45/-60/-30) SYM LAM. FAILURE SURF.
T300/5208
 $LAYER NNL=20,TH=0.,30.,60.,45.,75.,90.,-75.,-45.,-60.,-30.,
 -30.,-60.,-45.,-75.,90.,75.,45.,60.,30.,0.,
 PLNM=20*1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRAIN                  SUPERPOSE  -.5
THEEND
```

Output: Figures A-9 through A-11.

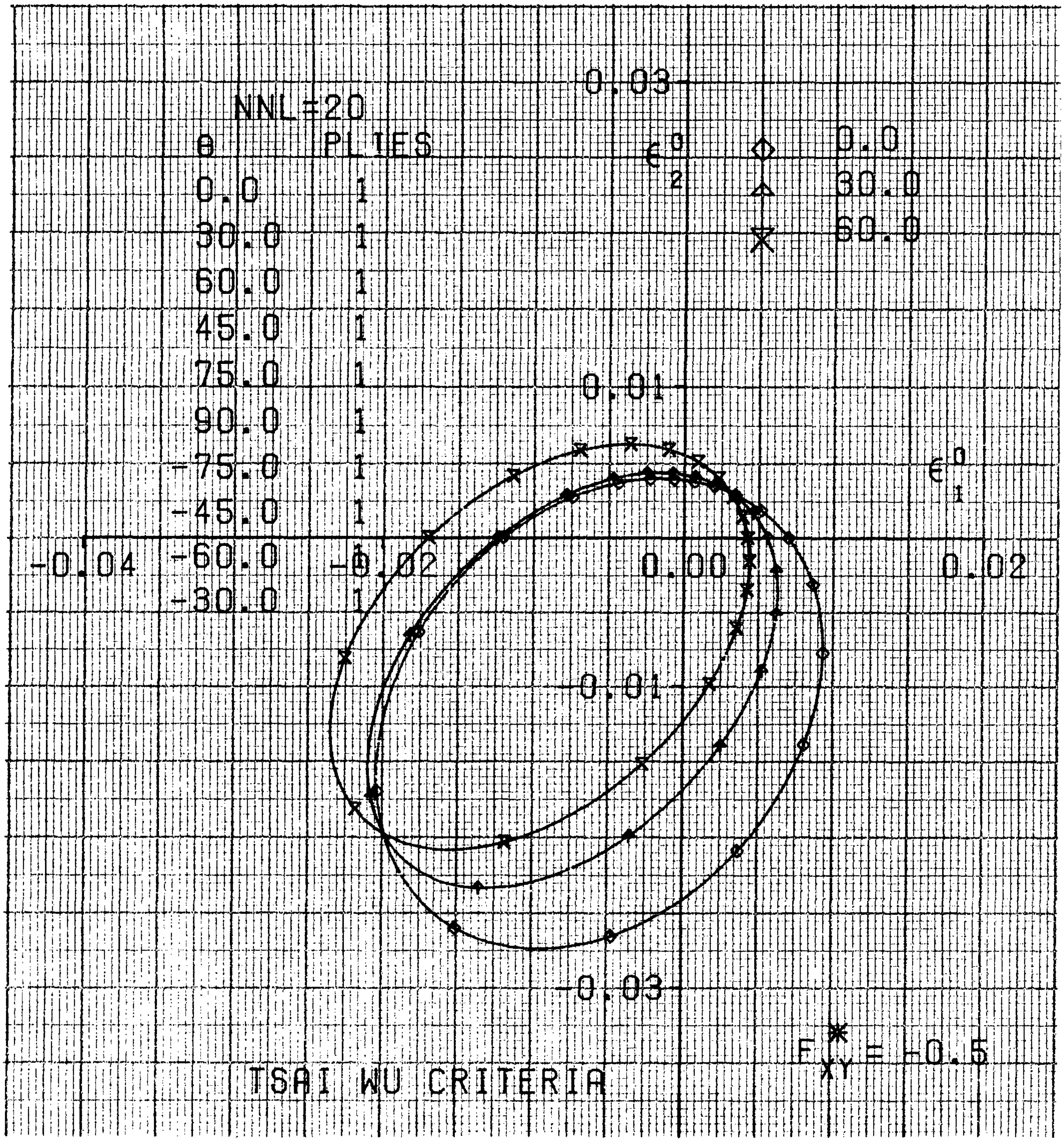


Figure A-9: Failure Envelopes of 0°, 30° and 60° Plies in $(0/90/\underline{+}30/\underline{+}45/\underline{+}60/\underline{+}75)_s$ - Laminate in Principal Strain Space.

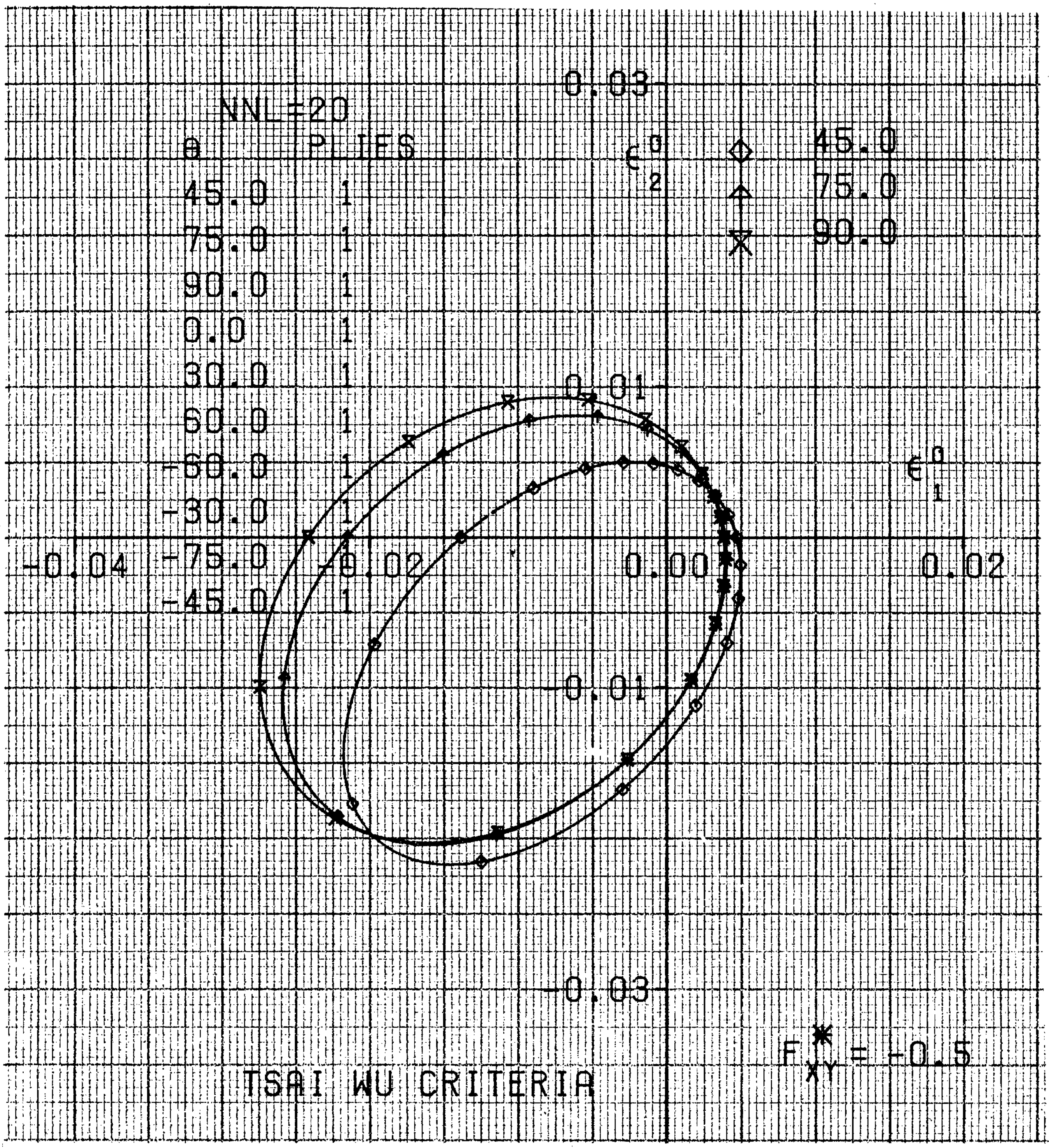


Figure A-10: Failure Envelopes of 45°, 75° and 90° Plies in $(0/90/\underline{+}30/\underline{+}45/\underline{+}60/\underline{+}75)_s$ - Laminate in Principal Strain Space.

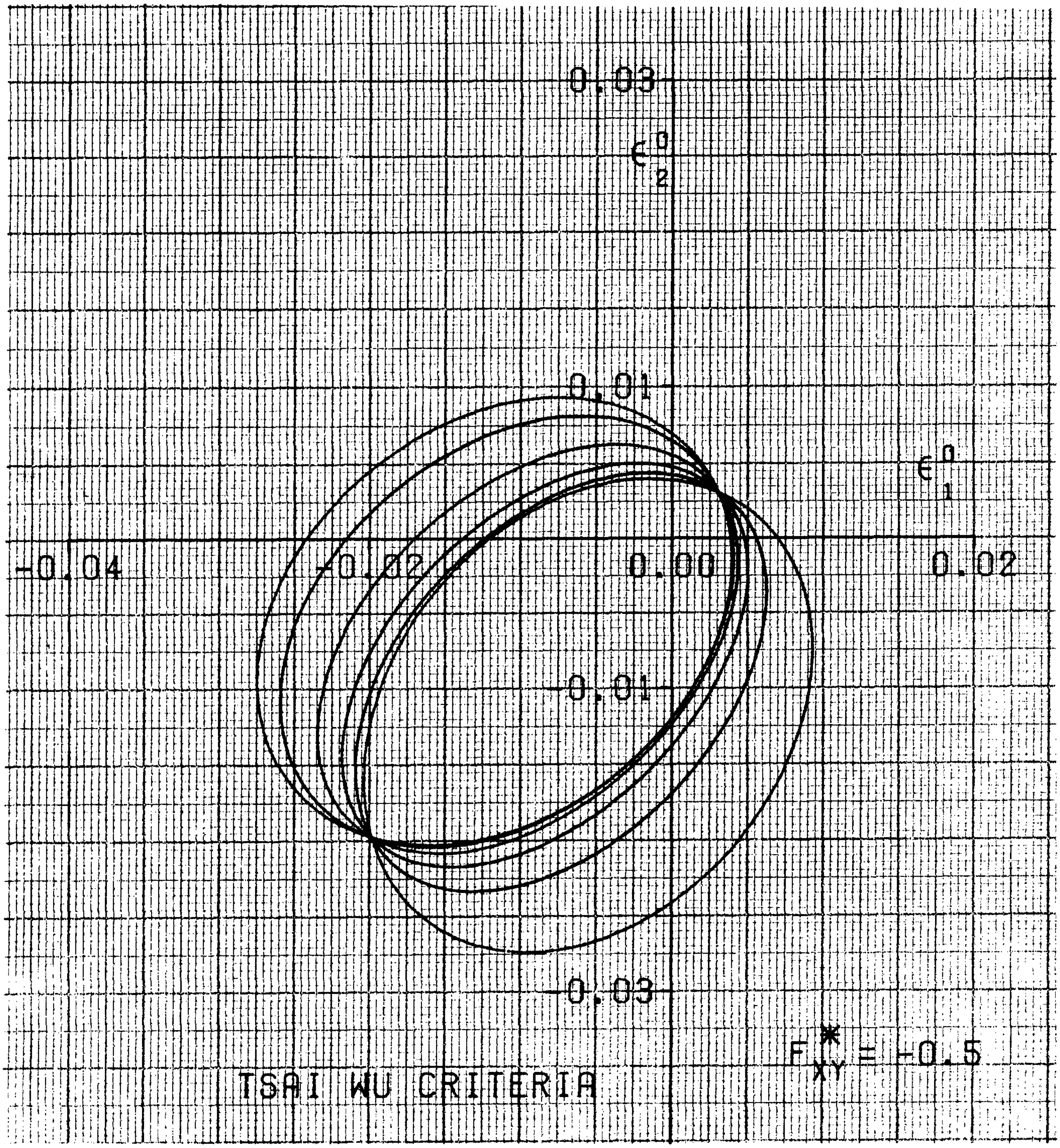


Figure A-11: Failure Envelopes of all the Ply Orientations for Laminate Considered in Figs. A-9, and A-10. Superposition of Figs. A-9 and A-10.

XI. Failure envelopes for $(0/90/\pm 45)_s$ - laminate made of T300/5208 graphite epoxy material on the basis of six failure theories in principal stress and principal strain spaces.

Input data:

```
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTSTART
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
TSAI WU   STRESS                              -.5
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
TSAI WU   STRAIN                              -.5
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
CHAMIS    STRESS                              -.7
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
CHAMIS    STRAIN                              -.7
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
HOFFMAN   STRESS                               0.
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
HOFFMAN   STRAIN                               0.
LAMINATE  INPLANE
PURE                                   STRNGTHPLTPLTFOLLOW
    (0/90/45/-45) LAMINATE
T300/5208
```

```
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
HILL       STRESS
LAMINATE   INPLANE
PURE                           STRNGTHPLTPLTFOLLOW
     (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
HILL       STRAIN
LAMINATE   INPLANE
PURE                           STRNGTHPLTPLTFOLLOW
     (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
MAXSTRAIN STRESS
LAMINATE   INPLANE
PURE                           STRNGTHPLTPLTFOLLOW
     (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
MAXSTRAIN STRAIN
LAMINATE   INPLANE
PURE                           STRNGTHPLTPLTFOLLOW
     (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
MAXSTRESS STRESS
LAMINATE   INPLANE
PURE                           STRNGTHPLTPLTEND
     (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
MAXSTRESS STRAIN
THEEND
```

Output: Figures A-12 through A-23.

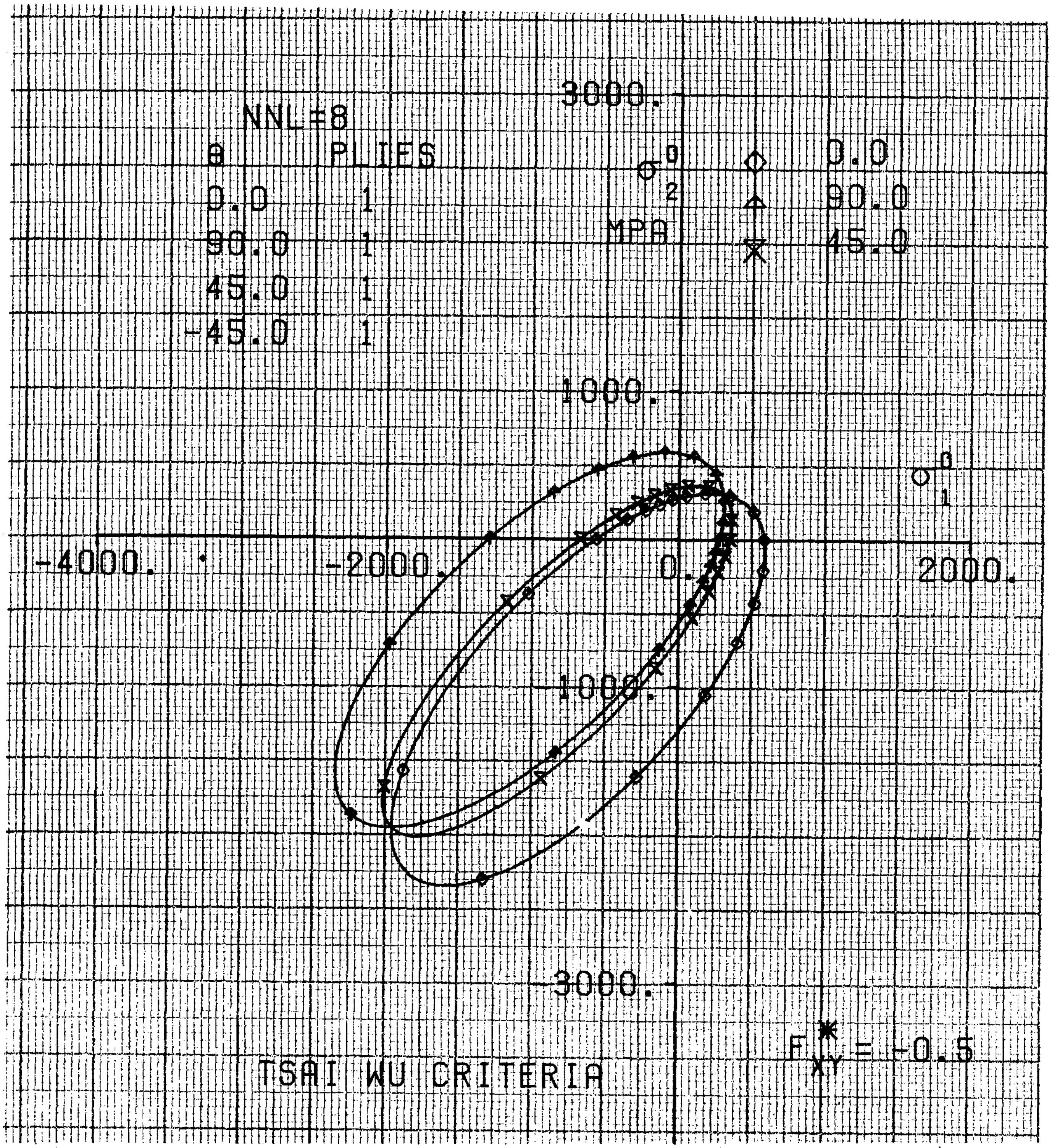


Figure A-12: Failure Envelopes for $(0/90/\underline{+}45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Tsai Wu Criterion.

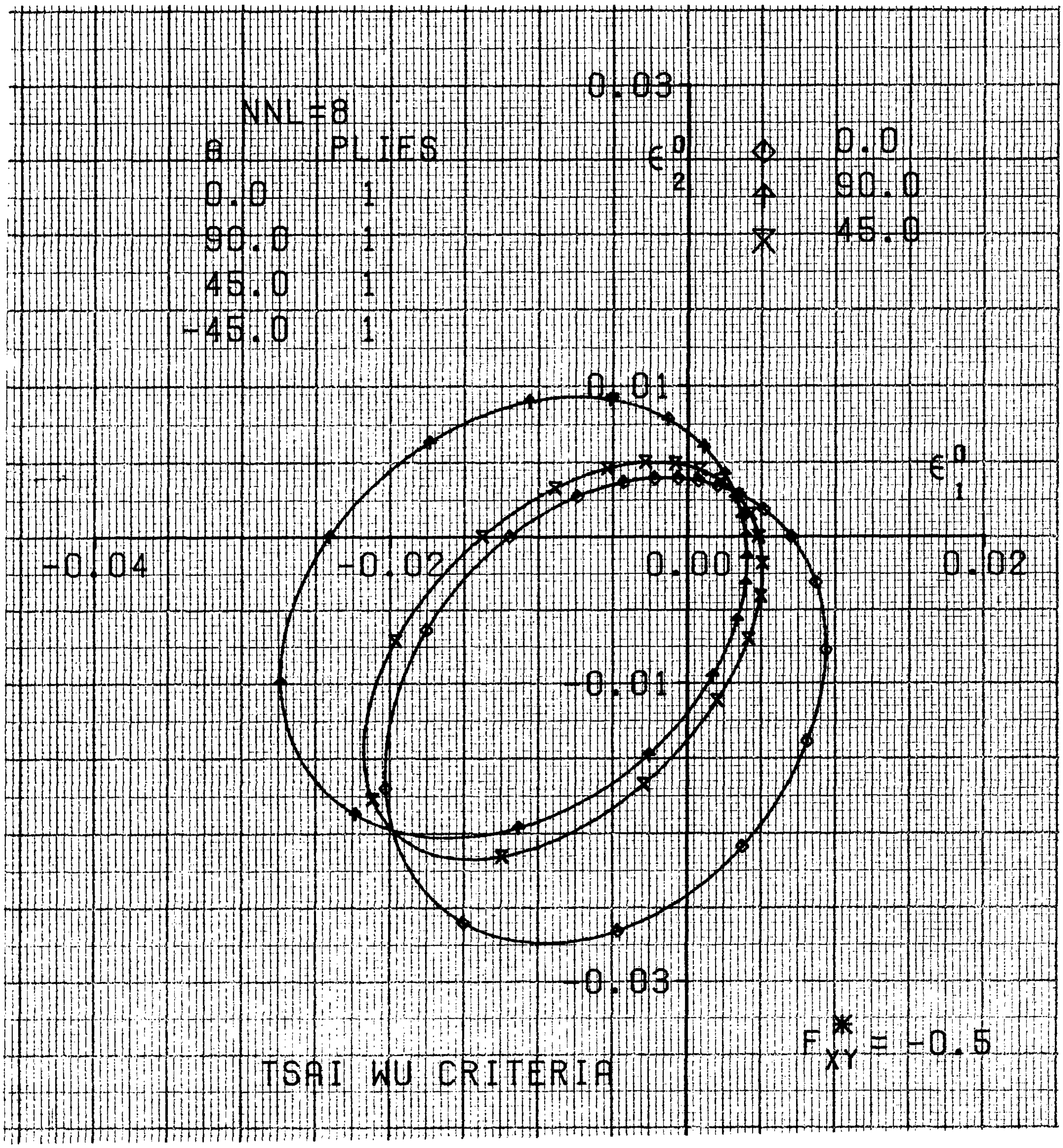


Figure A-13: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Tsai Wu Criterion.

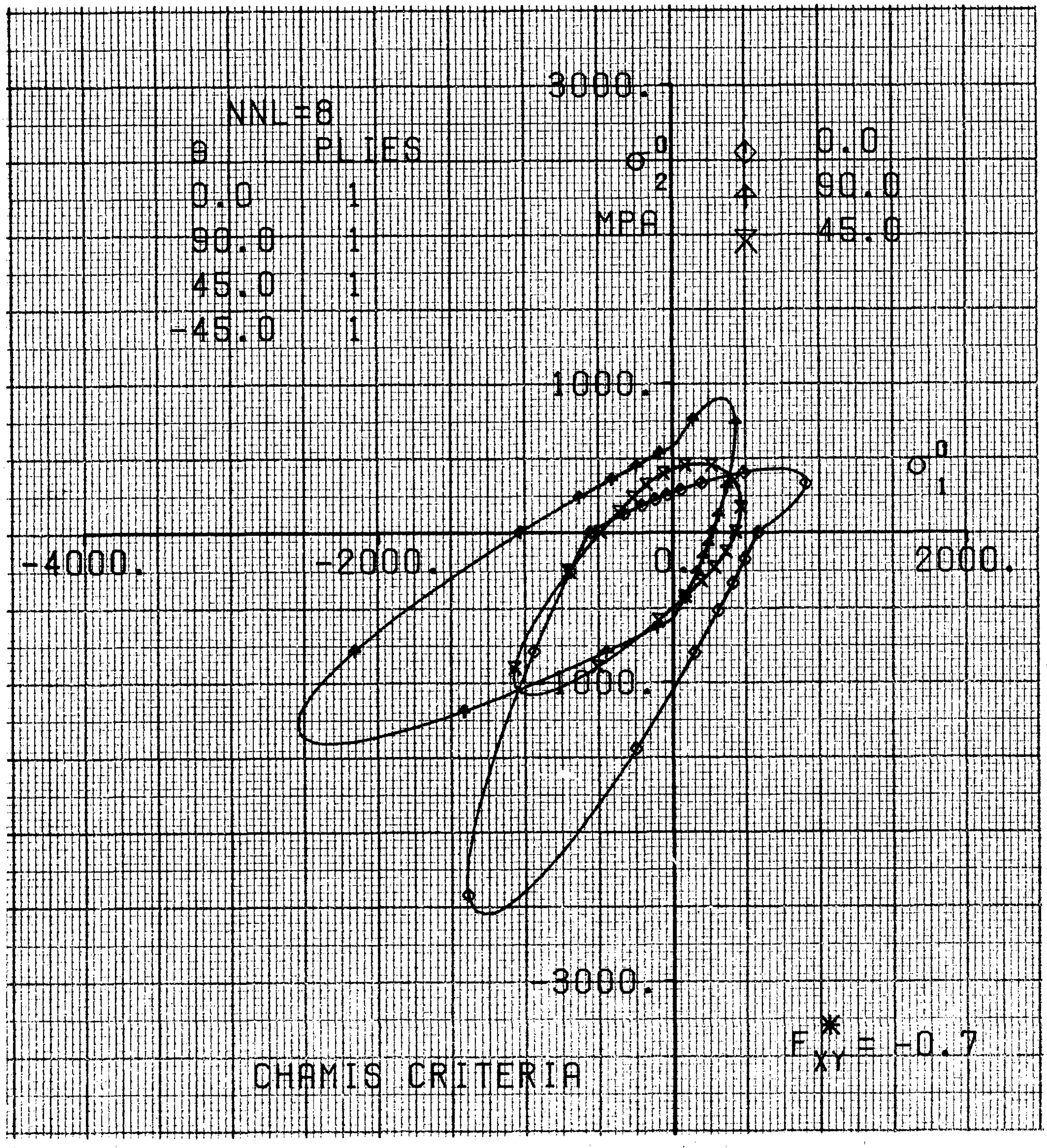


Figure A-14: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Chamis Criterion.

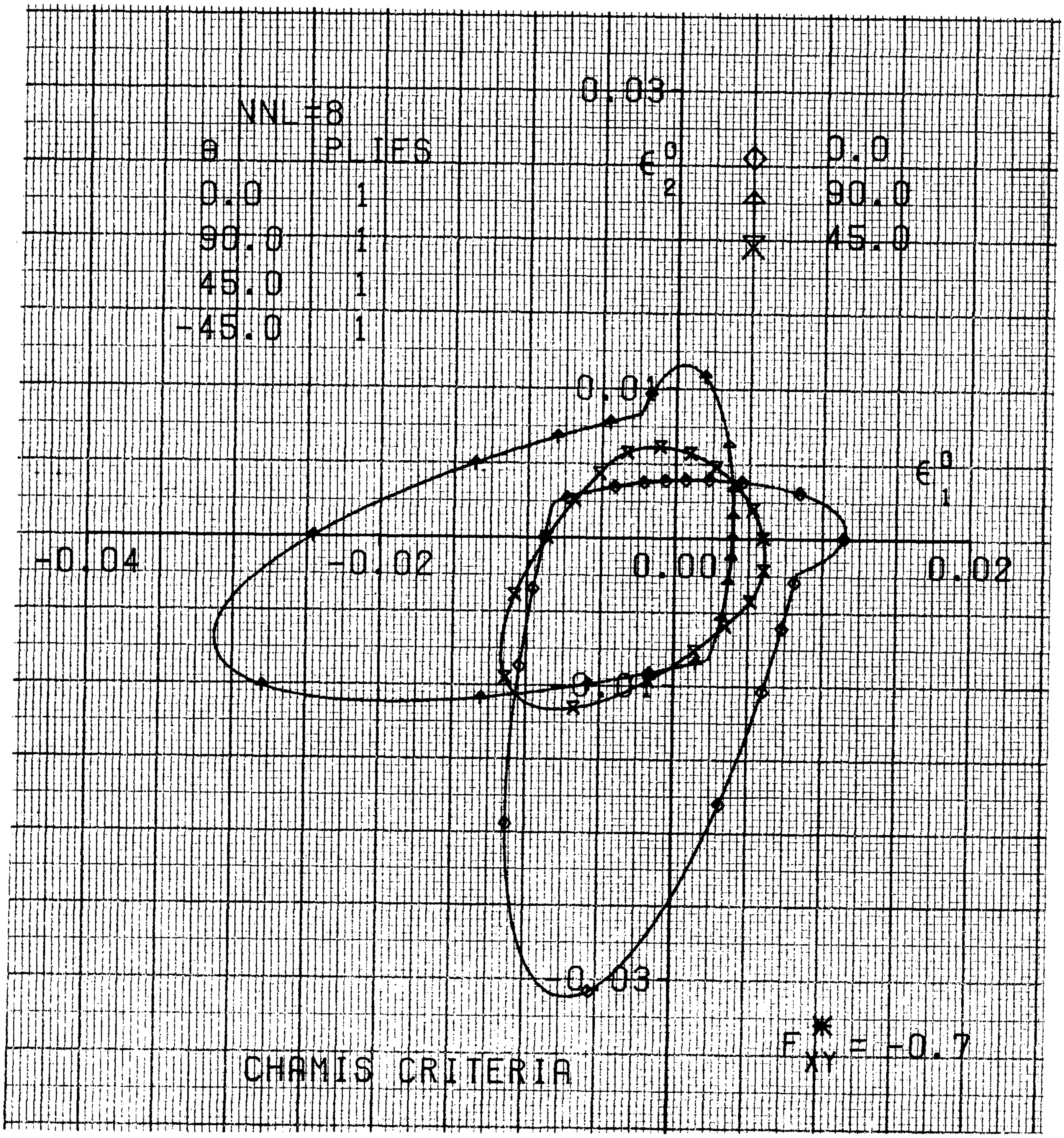


Figure A-15: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Chamis Criterion.

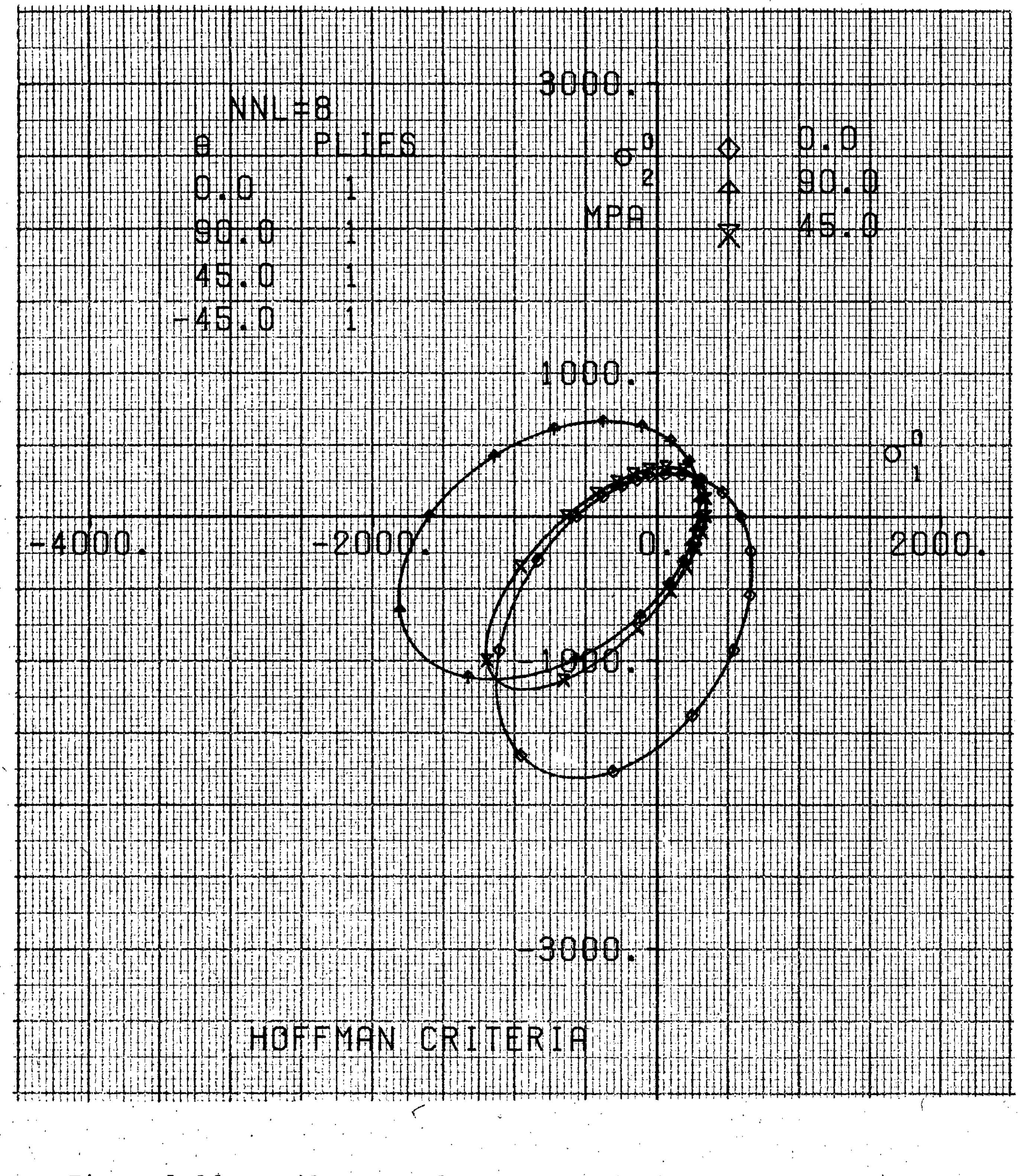


Figure A-16: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Hoffman Criterion.

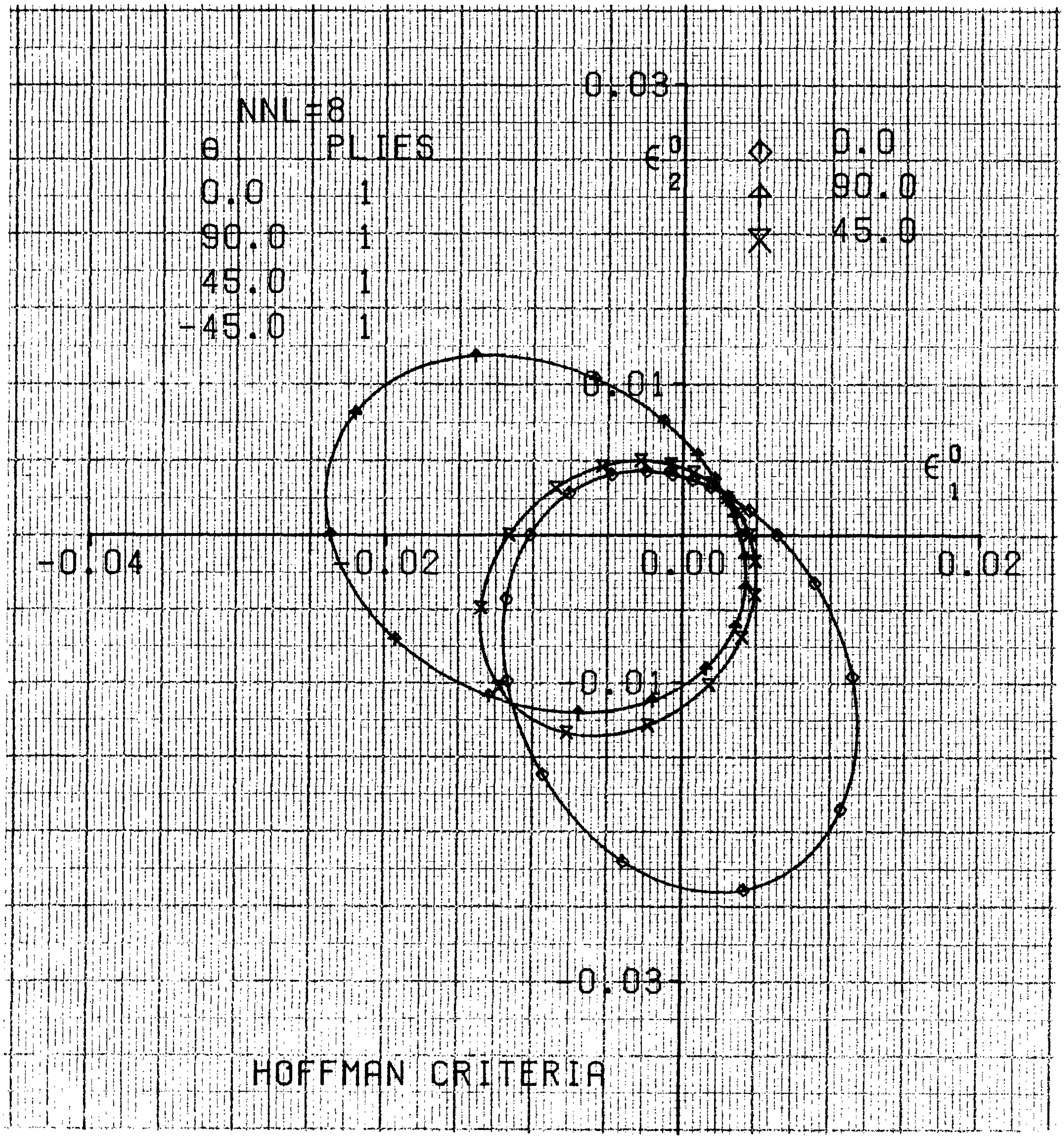


Figure A-17: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Hoffman Criterion.

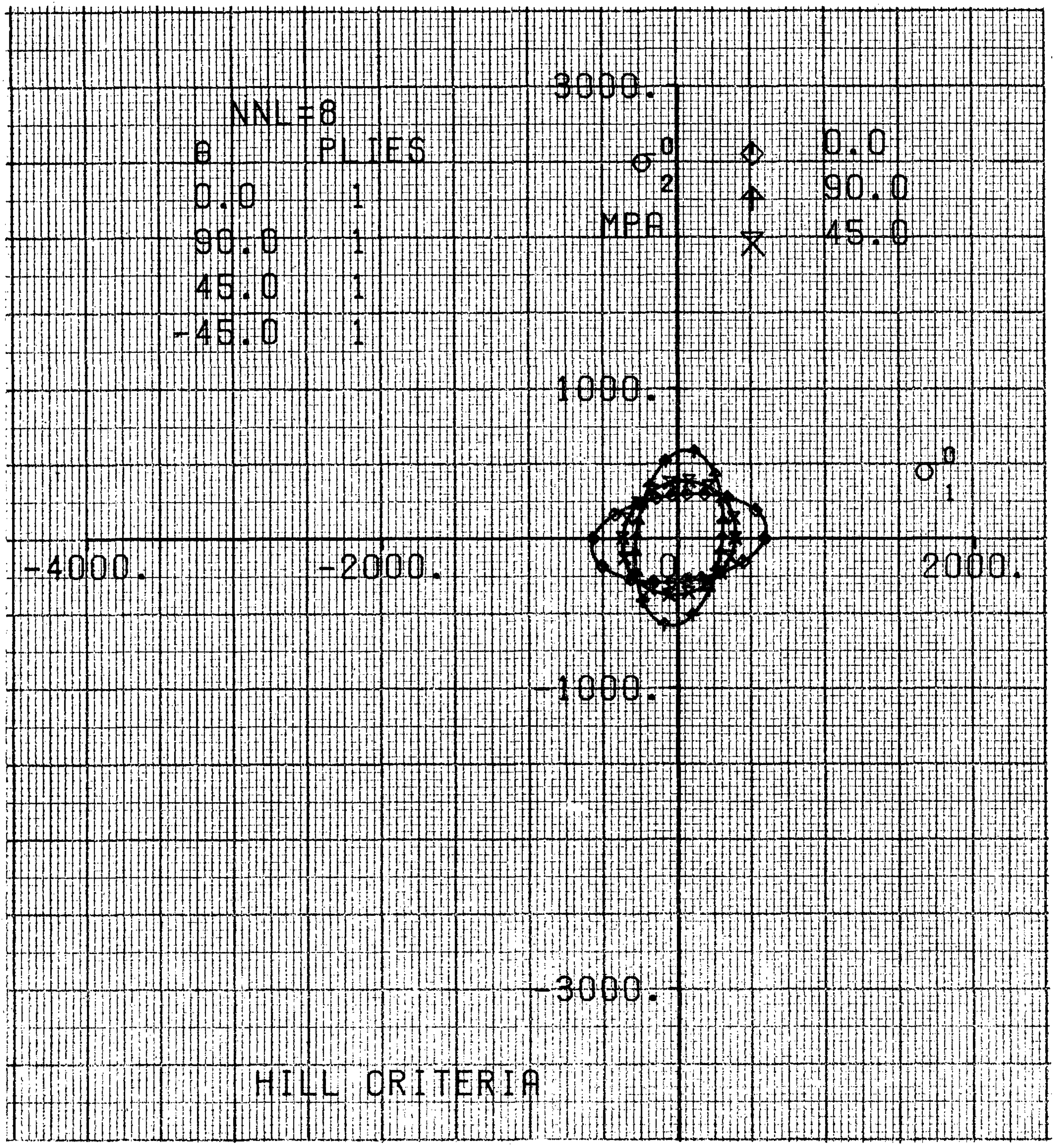


Figure A-18: Failure Envelopes for $(0/90/\pm 45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion.

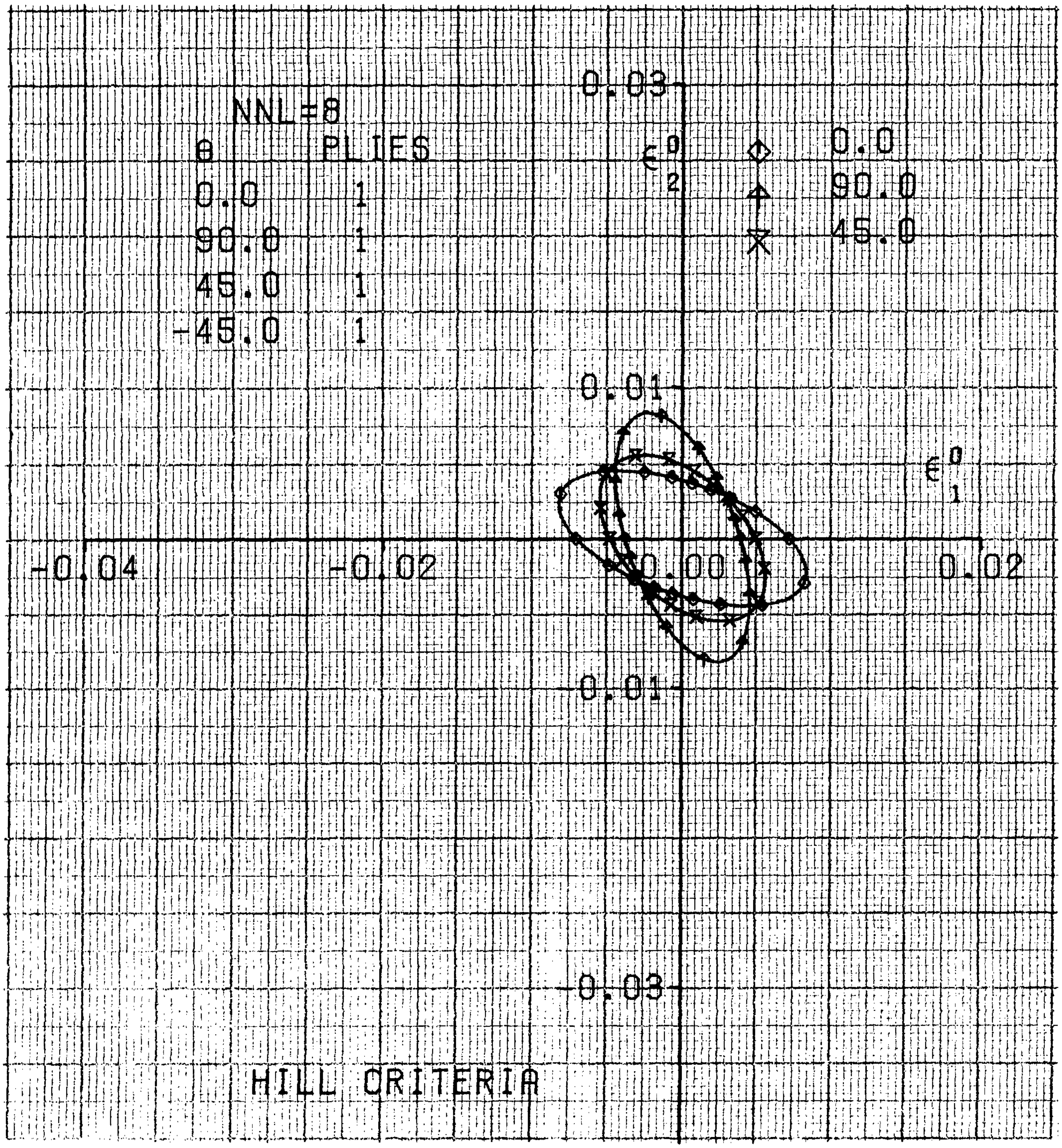


Figure A-19: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Hill Criterion.

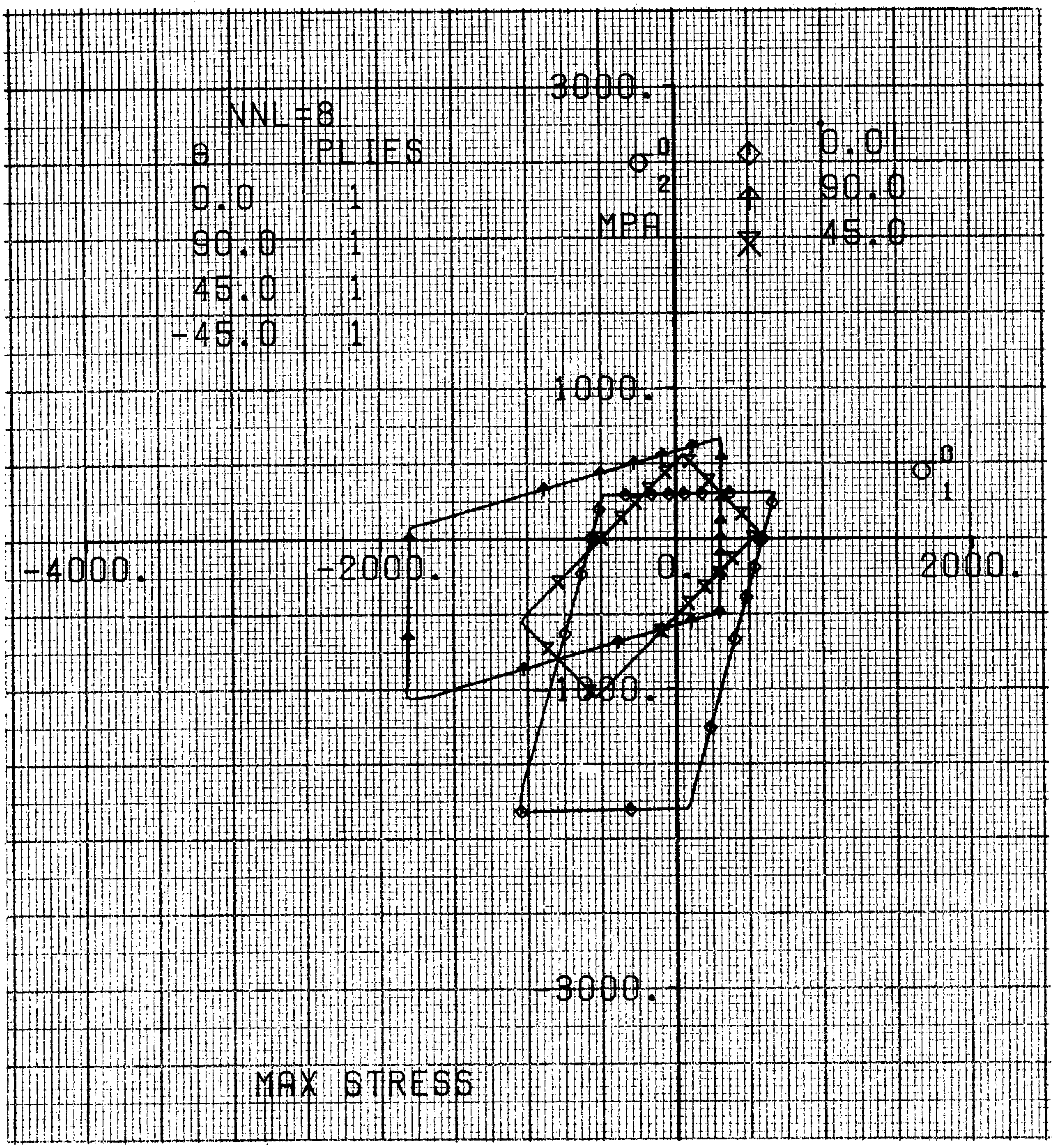


Figure A-20: Failure Envelopes for $(0/90/\pm45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Max. Stress Criterion.

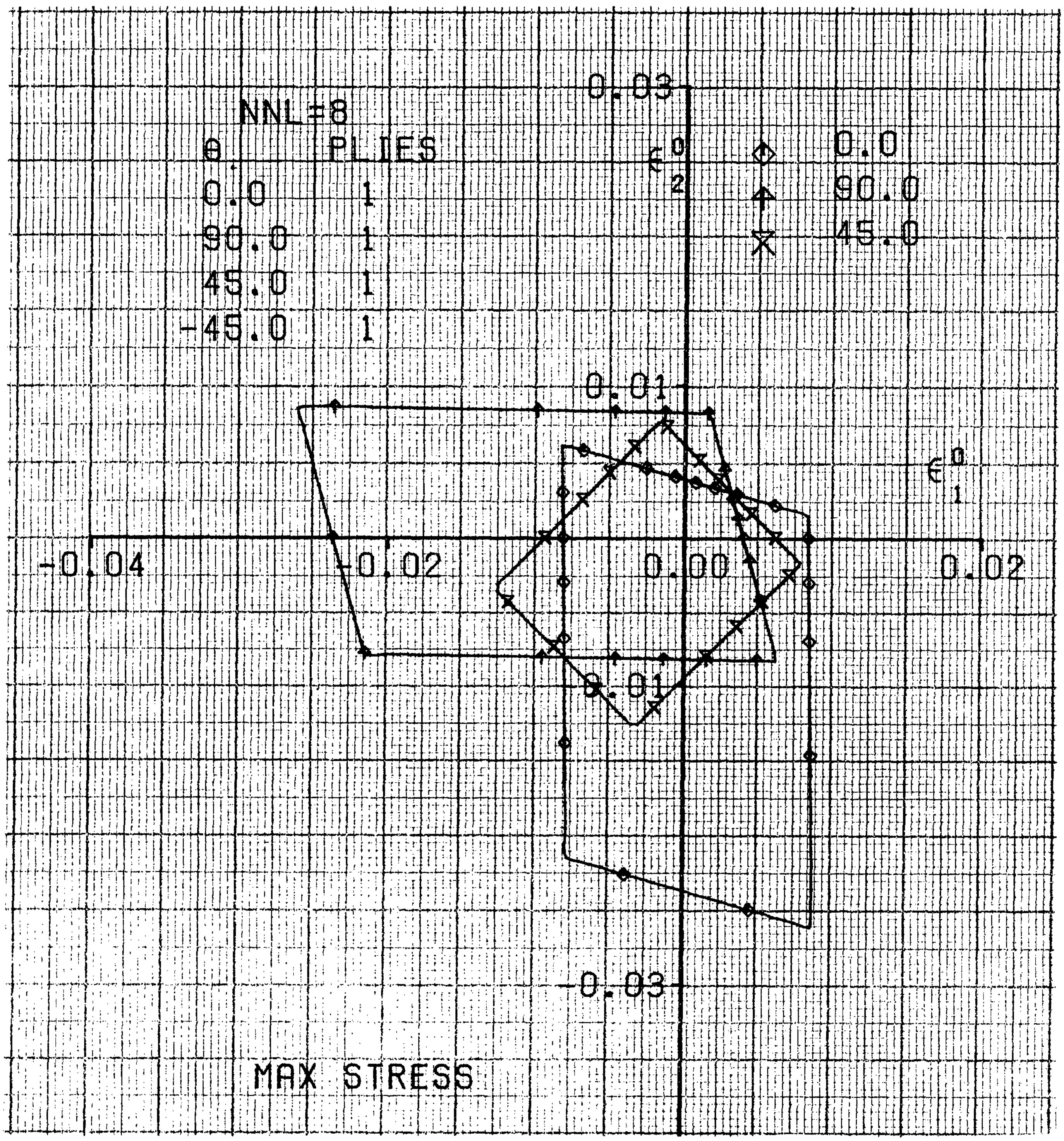


Figure A-21: Failure Envelopes for $(0/90/\underline{+}45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Max. Stress Criterion.

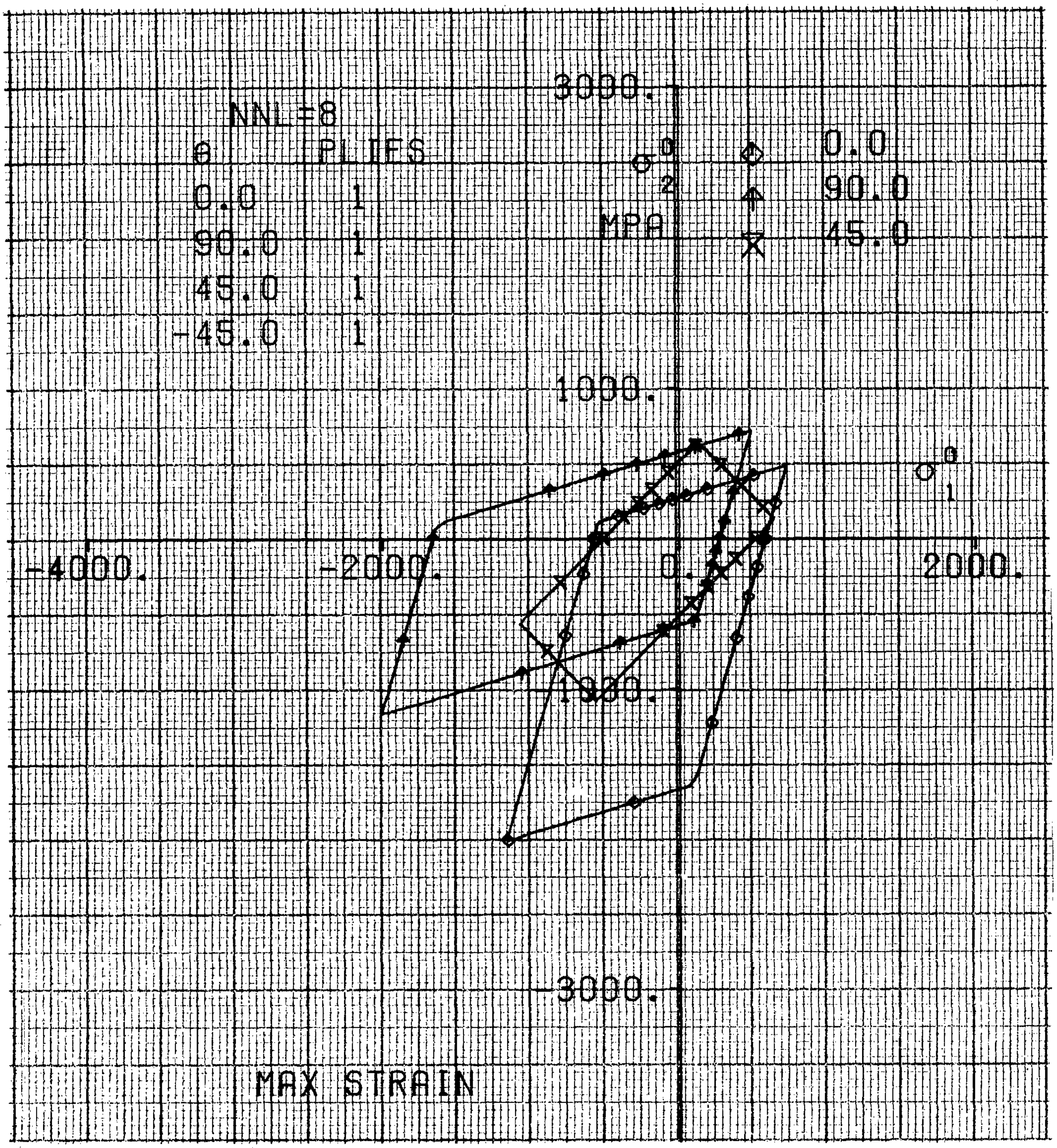


Figure A-22: Failure Envelopes for $(0/90/\pm 45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Max. Strain Criterion.

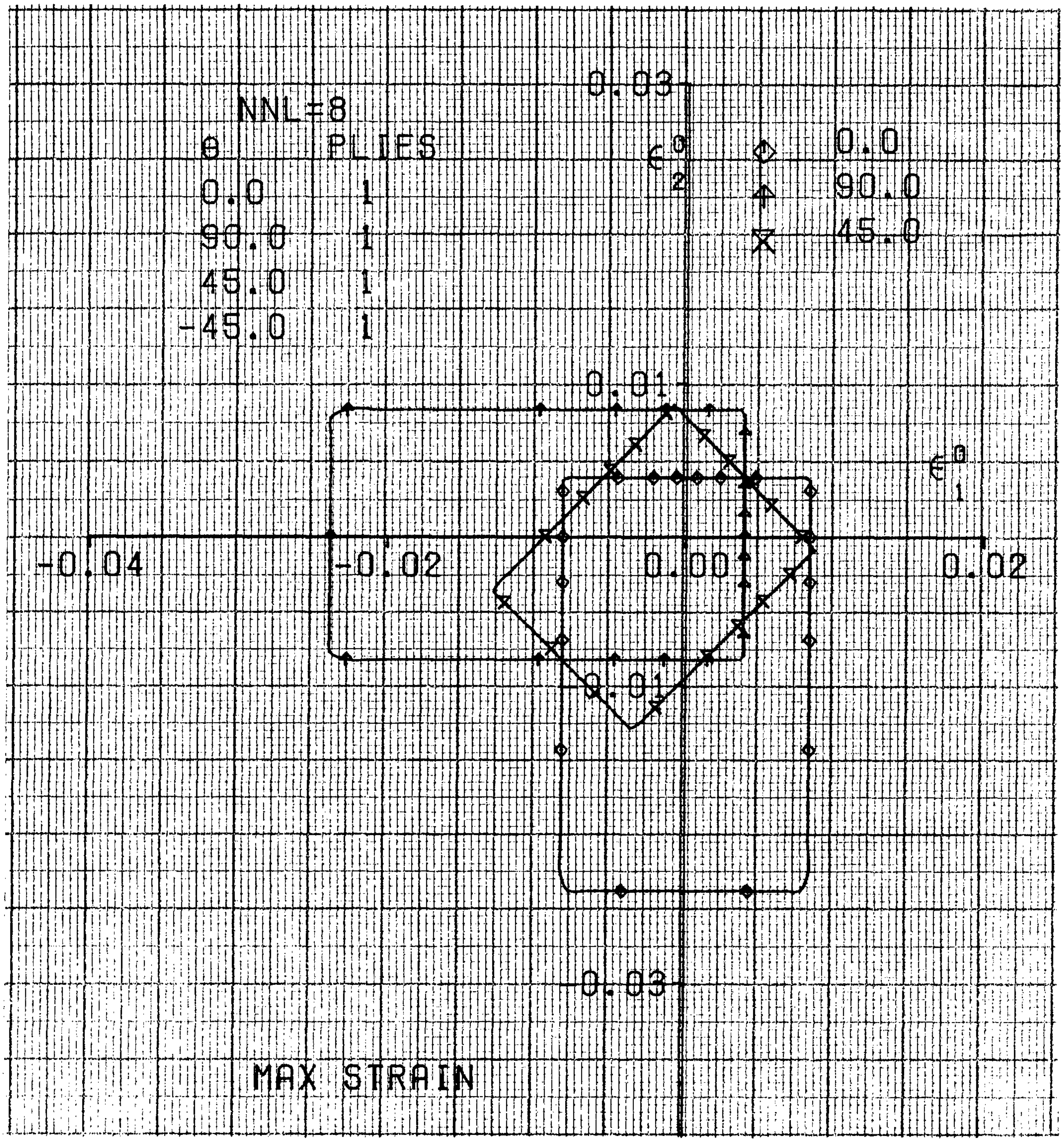


Figure A-23: Failure Envelopes for $(0/90/\pm 45)_s$ - Laminate of T300/5208 Material in Strain Space on the Basis of Max. Strain Criterion.

XII. Change of Scale:

The scale of the coordinate axis of Figure (A-18) has been reduced to 1/2 by the use of FCTRS.

Input data:

```
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTONE
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,
 NLDCN=1  $
HILL      STRESS                                                  .5
THEEND
```

Output: Figure A-24.

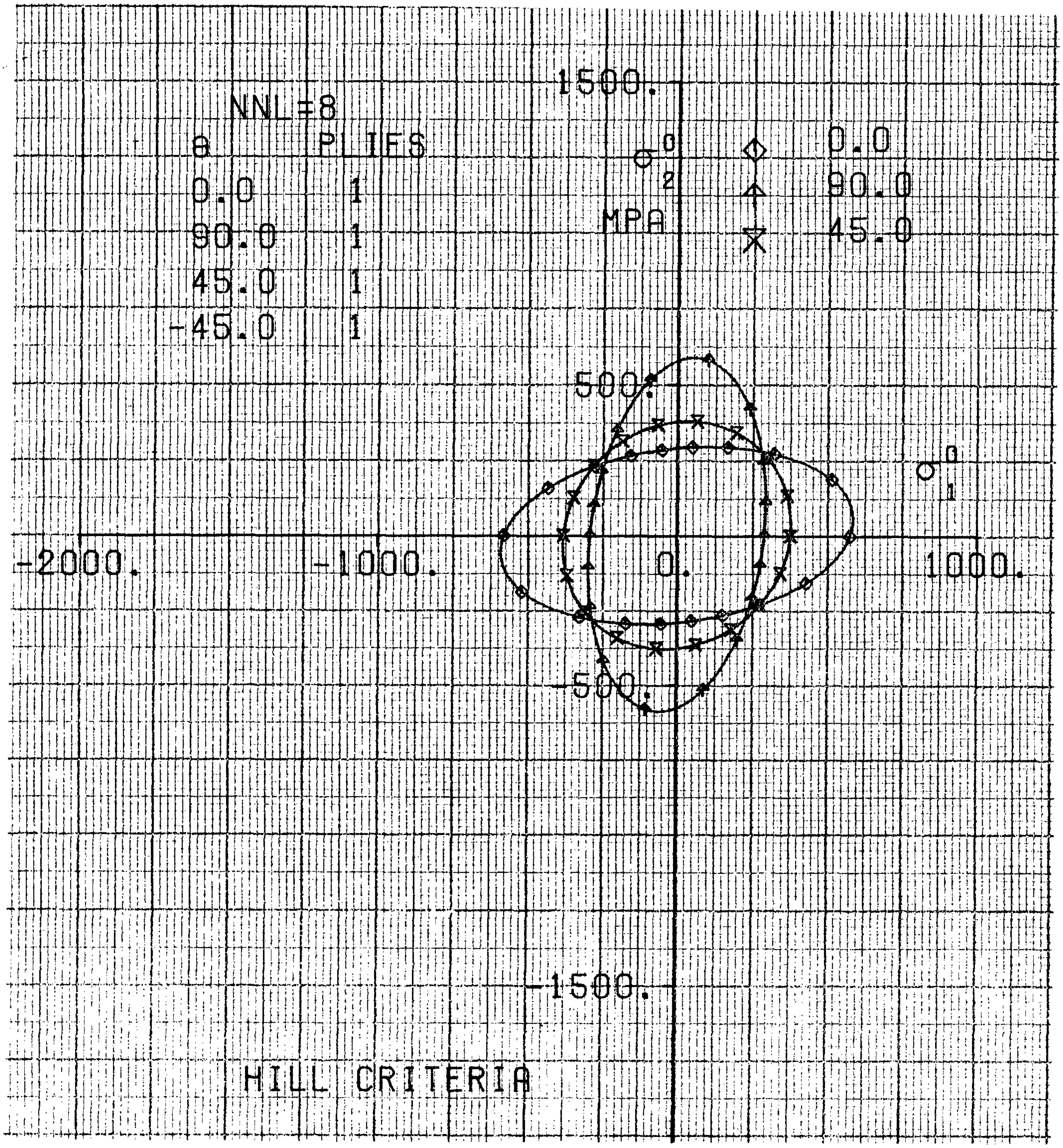


Figure A-24: Failure Envelopes for $(0/90/\pm45)_s$ Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion. Same Figure as A-18, with Scale Reduced to Half.

XIII. Reduce the size of the Figure A-23 to 75% using FCTRF command.

Input data:

```
LAMINATE  INPLANE
PURE                              STRNGTHPLTPLTONE
    (0/90/45/-45) LAMINATE
T300/5208
 $LAYER NNL=8,TH=0.,90.,45.,2*-45.,45.,90.,0.,PLNM=8*1.,DT=0.,C=0.,NLDCN=1   $
HILL       STRESS                                                   .5         .75
```

Output:

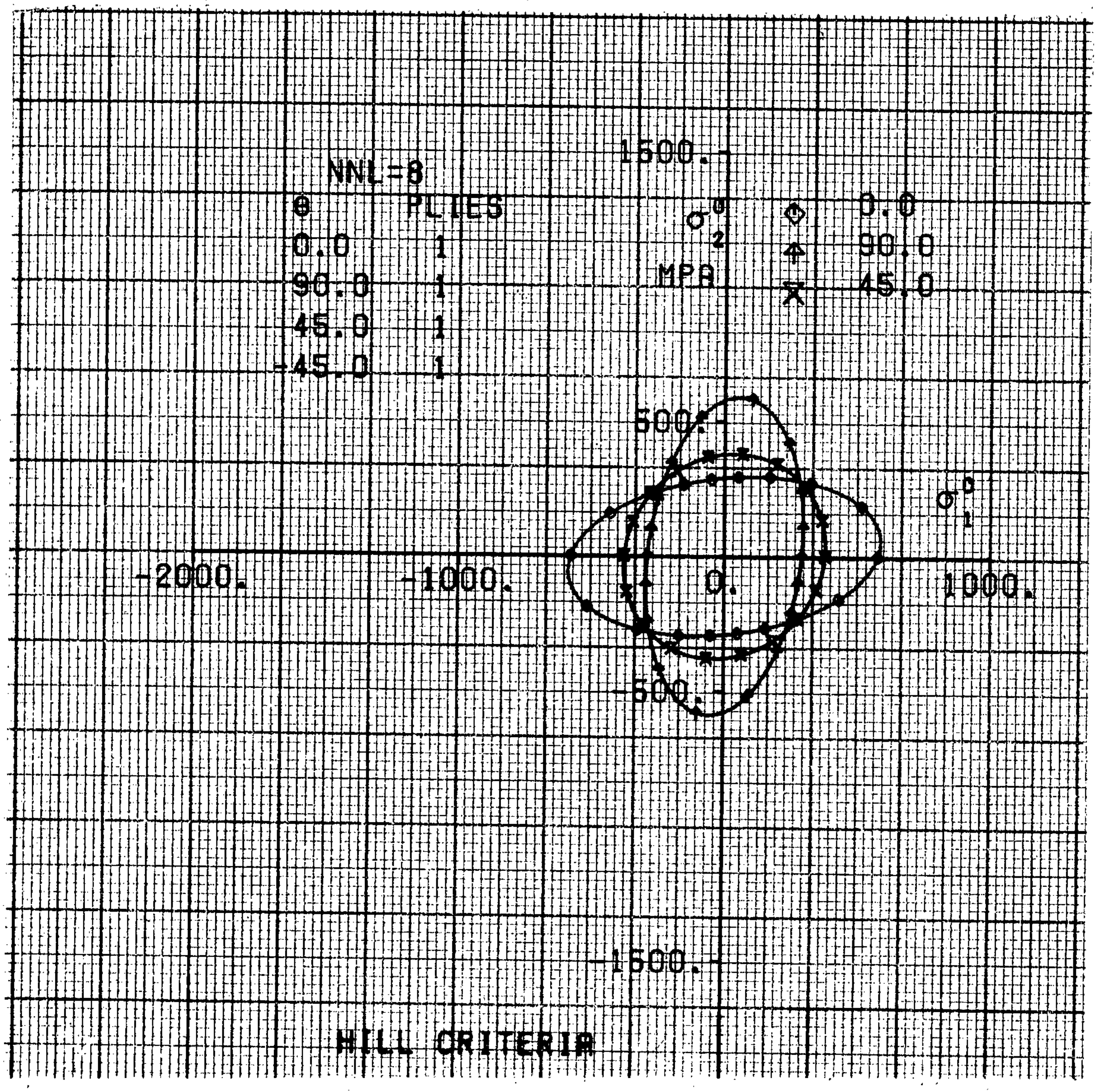


Figure A-25: Failure Envelopes for $(0/90/\pm 45)_s$ - Laminate of T300/5208 Material in Stress Space on the Basis of Hill Criterion. Figure Size of A-23 Reduced to 75%.

XIV. Failure surfaces for isotropic materials:

1. Isotropic material with $\nu = .5$ and $X' = X$, $Y' = Y$, in principal strain space for $F^*_{xy} = -0.5$
2. Isotropic material with $\nu = 0$, (0.5) and $X' = X$, $Y' = Y$, in principal stress space for $F^*_{xy} = 0$, (-.5).
3. Isotropic material with $\nu = 0$ and $X' = X$, $Y' = Y$, in principal stress space, $F^*_{xy} = -.5$.
4. Isotropic material with $\nu = 0$, (.5) and $X' = 2X$, $Y' = 2Y$, in principal stress space for $F^*_{xy} = -.5$, (0).

Input data:

```
NEWMTRLS  SI
 $LAMDATA NNM=4,EX=4*69.,EY=4*69.,VX=0.,.5,0.,.5,
 ES=34.5,23.,34.5,23.,ALFX=4*0.,ALFY=4*0.,BTAX=4*0.,
 BTAY=4*0.,X=4*400.,XD=2*400.,2*800.,Y=4*400.,
 YD=2*400.,2*800.,S=4*230.,SH=.000125  $
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTSTART
 V=.5,X=XD
B4/5505
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRAIN              SUPERPOSE  -.5                0.5
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
  V=0,X=XD,FSXY=-.5
T300/5208
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRESS              SUPERPOSE  -.5     MULTICURV  0.25
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
 V=.5,X=XD,FSXY=.0
B4/5505
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRESS              SUPERPOSE  0.0                0.25
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
  V=0,X=XD,FSXY=-.5
T300/5208
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRESS              SUPERPOSE  -.5                0.25
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTFOLLOW
  V=0,XD=2X,FSXY=-.5
AS/3501
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRESS              SUPERPOSE  -.5     MULTICURV  0.5
LAMINATE  INPLANE
PURE                          STRNGTHPLTPLTEND
  V=.5,XD=2X,FSXY= 0.0
SCOTCHPLY
 $LAYER NNL=1,TH=0.,PLNM=1.,DT=0.,C=0.,NLDCN=1  $
TSAI WU   STRESS              SUPERPOSE  0.0                0.5
THEEND
```

Output: Figures A-26 through A-29.

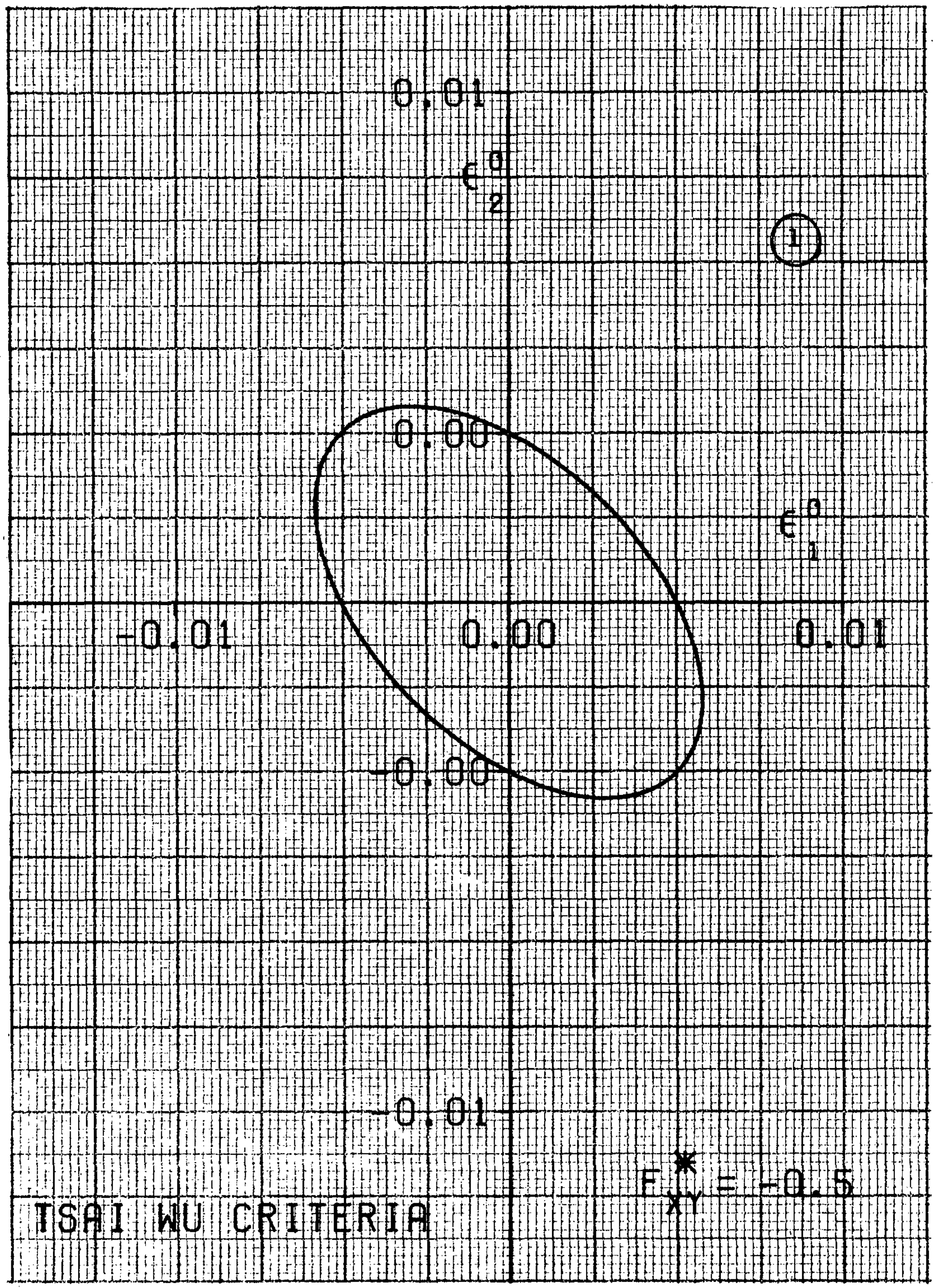


Figure A-26: Failure Surface for an Isotropic Material in Principal Strain Space, $\nu = 0.5$.

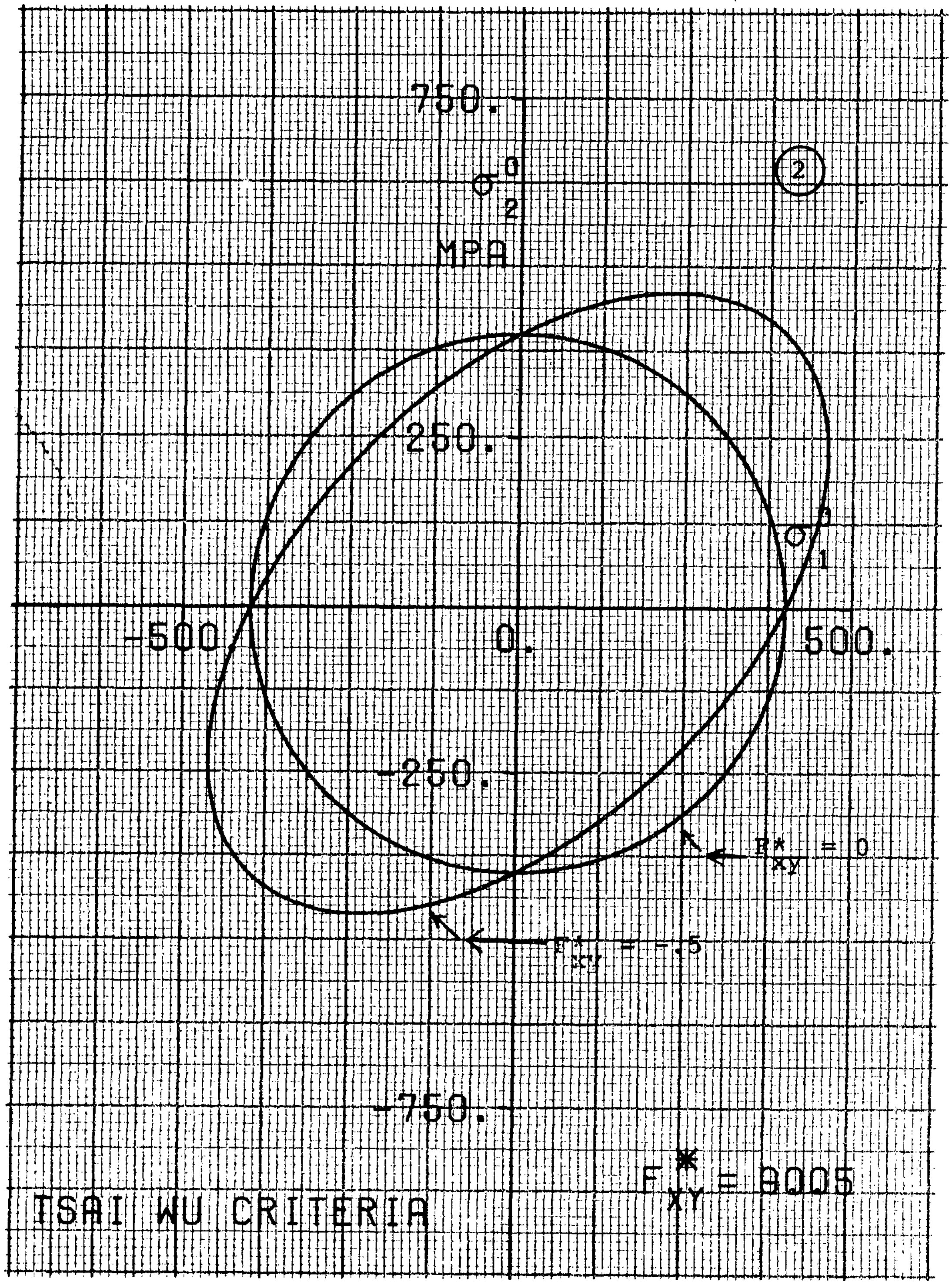


Figure A-27: Failure Surfaces for an Isotropic Material in Principal Stress Space $\nu = 0$ (-.5) and $F^*_{xy} = 0$, (-.5).

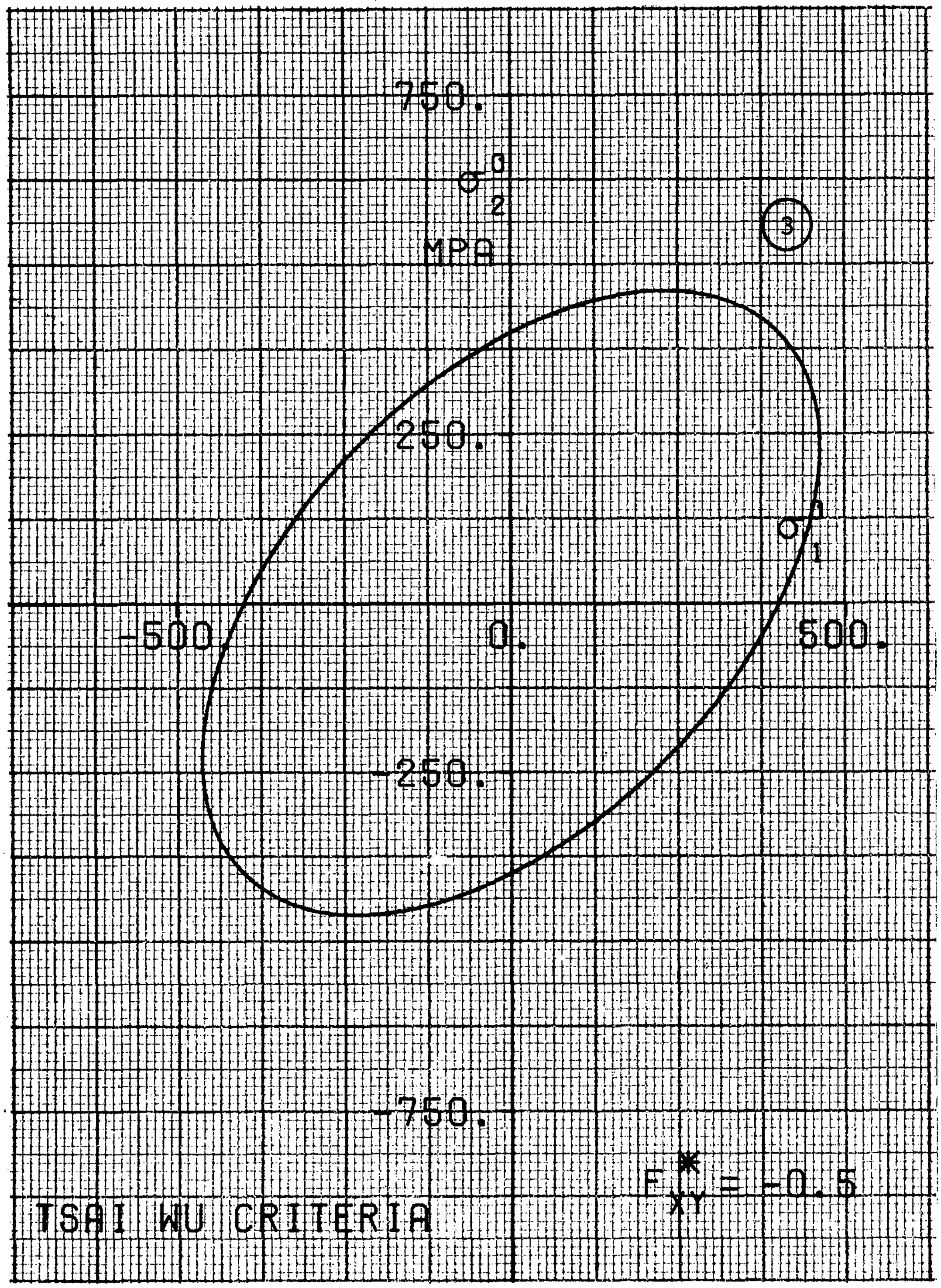


Figure A-28: Failure Surface for an Isotropic Material in Principal Stress Space, ν = 0.

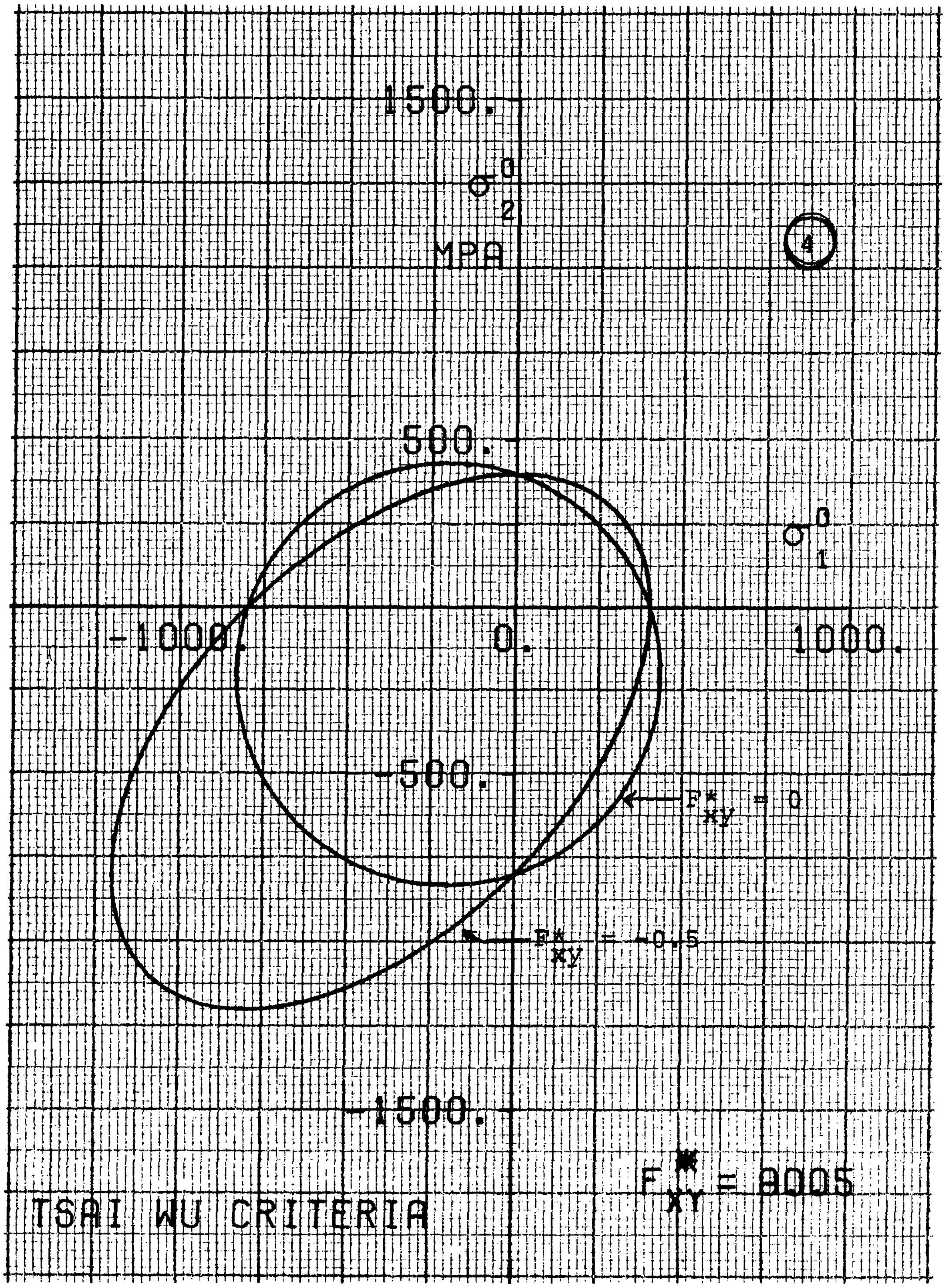


Figure A-29: Failure Surfaces for an Isotropic Material with $\nu = 0$, $(.5)$, $X' = 2X$, $Y' = 2Y$ in Principal Stress Space for $F^*_{xy} = 0$, $(-.5)$.

APPENDIX B

CURRENT AFWAL/MLBM LAMINATE PROGRAMS

MAY 1983

	SYMMETRIC ONLY	BALANCED ONLY	IN-PLANE STIFFNESS	FLEXURAL STIFFNESS	LAMINATE STRENGTH	THERMAL EFFECT	HYGROSCOPIC EFFECT	HARDCOPY MEDIUM	STORAGE MEDIUM	OPTIMIZATION (SIZING)	SANDWICH CORE	HYBRID MATERIALS
FORTRAN (CDC)			X	X	1,2	X	X	4	10		X	X
TI CC-40	X		16	16	16			16	16	14,15	16	
TI-59 W/ COMBO CARDS	X		X	X	1			5	11		X	14
APPLE II*			X	X	1,3	X	X	6	12		X	
TIMEX 1000 (+16K)	X							7	13	14		
TRS-80 PC-1	X		X	X	1			5	13		X	
SHARP PC-1500 (+8K)	X		X	X	1			5,8	13		X	
EPSON HX-20	X		X	X	1			8,9	13	14	X	
PANASONIC HHC (4K)	X		X	X	1			5			X	

1. QUADRATIC (TSAI-WU) FAILURE CRITERION
2. REPORT IN PROGRESS INCLUDES ADDITIONAL FAILURE CRITERIA:
   a. CHAMIS
   b. HOFFMAN
   c. HILL
   d. MAX STRESS
   e. MAX STRAIN
3. MAX STRAIN FAILURE CRITERION
4. LINE PRINTER AND CALCOMP FAILURE SURFACE PLOTS
5. PRINTING CRADLE
6. 80 COLUMN PRINTER
7. TIMEX/SINCLAIR COMPATIBLE PRINTERS
8. ALSO PLOTS FAILURE SURFACES
9. BUILT-IN PRINTER
10. PUNCHED CARDS/MAG. TAPE
11. REQUIRES CUSTOM AFWAL/MLBM ROM MODULE AND MAG. CARDS
12. 5 1/4" DISK
13. AUDIO CASSETTE TAPE
14. IN-PLANE LOADS ONLY
15. BALANCED LAMINATES ONLY
16. PROGRAMMING IN PROGRESS

* ALSO AVAILABLE ARE DISKS CONTAINING PROGRAMS TO ANALYZE BEAMS, SHAFTS, PRESSURE VESSELS, MOISTURE ABSORPTION AND DESORPTION, CURING OF EPOXY-MATRIX COMPOSITES, AND LIFE PREDICTION (COMING SOON).

CURRENT AFWAL/MLBM LAMINATE PROGRAMS DOCUMENTATION

Machine	Title	Report No.
Fortran (CDC)	"A Digital Algorithm for Composite Laminate Analysis - Fortran", S. Soni	AFWAL-TR-81-4073
TI CC-40	Report in Progress	
TI-59 w/Combo Cards	"Revised Instructions for TI-59 Combined Card/Module Calculations for In-Plane and Flexural Properties of Symmetric Laminates", S. Donaldson	AFWAL-TR-82-4081 AFWAL-TR-81-4183 (Hybrid)
Apple II	"An Apple Computer Program for the Analysis of Composite Laminates", H. Chai	AFWAL-TR-83-4041
Timex/Sinclair 1000	"Composite Laminate Weight Optimization on the Timex-Sinclair 1000 Microcomputer", G. Flanagan	AFWAL-TR-83-4017
TRS-80 PC-1	"Radio Shack TRS-80 Pocket Computer Solutions to Composite Materials Formulas", W. Park and T. Massard	AFWAL-TR-81-4074
Sharp PC-1500	"Sharp PC-1500 Pocket Computer Solutions to Composite Materials Formulas", W. Park and T. Massard	AFWAL-TR-83-4016
Epson HX-20	Report in Progress	
Panasonic HHC	Report in Progress	